Sediment Transport, Fingerprinting and Background Conditions in the LPRSA and at RM 10.9

April 19, 2012

Summary of Evidence Supporting Tierra Responsibility for RM10.9 Costs

- Modeling and salinity measurements indicate upstream transport to and beyond RM 10.9
  - Physical water column program data indicate salt front reaching beyond RM 10.2 during low flows
  - 2 ppt isohaline observed near RM 10.9 during low flow periods (Chant et al., 2010) and confirmed by CPG modeling results
  - 0.5 ppt isohaline extends beyond RM 10.9 more regularly (EPA/HQI modeling results)
- Enhanced upstream transport during period of 2,3,7,8-TCDD discharge at Lister Avenue is expected for two reasons (Chant, et al., 2010)
  - "Severe" drought and low flows
  - Deeper channel would have allowed greater salinity intrusion
- Elevated levels of 2,3,7,8-TCDD extend to the low flow limit of salinity intrusion (CPG LRC Report)
- Mass of 2,3,7,8-TCDD centered at Lister Ave with no second peak near RM 10.9, and a distribution consistent with upstream transport mechanisms
- Dioxin/Furan fingerprint at RM 10.9 matches Lister Ave.
- 2,3,7,8-TCDD to DDx ratio matches downstream sediments
- Human health cancer risks predominantly from TCDD (AECOM risk tool)
- Influence of regional background levels on other COPCs

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UPSTREAM TRANSPORT

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Upstream Transport

- Upstream sediment transport occurs due to a combination of effects. Broadly:
  - Estuarine circulation
    - Vertical (or lateral) variations in tidally-averaged velocity and suspended sediment concentrations
  - Tidal pumping
    - Temporal correlation of velocity and suspended sediment over tidal cycle
    - Tidal asymmetry in bottom velocity is important in LPR, yielding a flood dominant bottom shear stress during low flows
- The Estuarine Turbidity Maximum (ETM)
  - High suspended solids zone associated with enhanced deposition, and by association, trapping of sorbed contaminants
  - Commonly taken as the limit of net upstream solids transport

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Estuarine Turbidity Maximum

- Typically, the ETM occurs at the convergence zone near the salt front
  - Other factors influence its location, such that the ETM may occur somewhat landward of the salt front

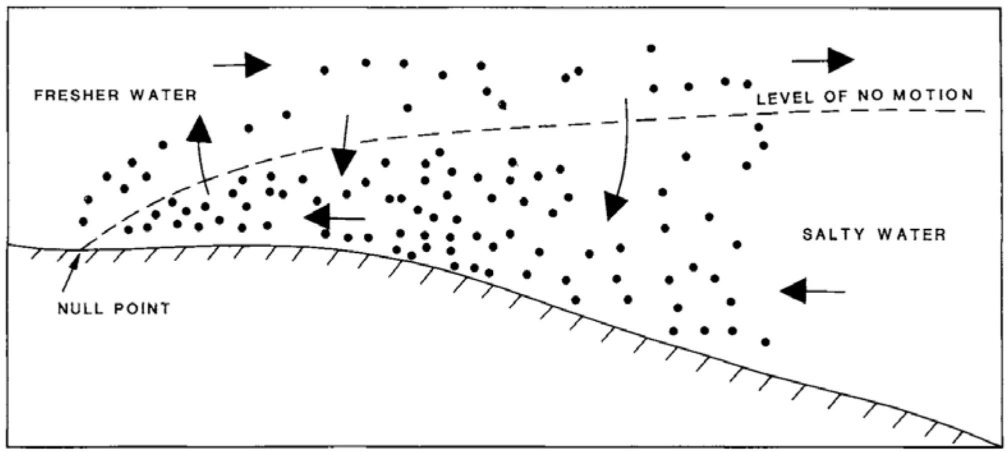


Fig. 14-8. Diagrammatic representation of the formation of the turbidity maximum by vertical gravitational circulation.

Dyer, 1995

- Associated with enhanced solids/contaminant trapping, but not necessarily the limit of upstream 2,3,7,8-TCDD transport

Observations of ETM near the “head of salt”

Survey started about 2 hours after high tide

Flow at Little Falls: 44 cfs (P ≈ 3.7%)

Flow at Little Falls: 11,700 cfs (P ≈ 99.9%)

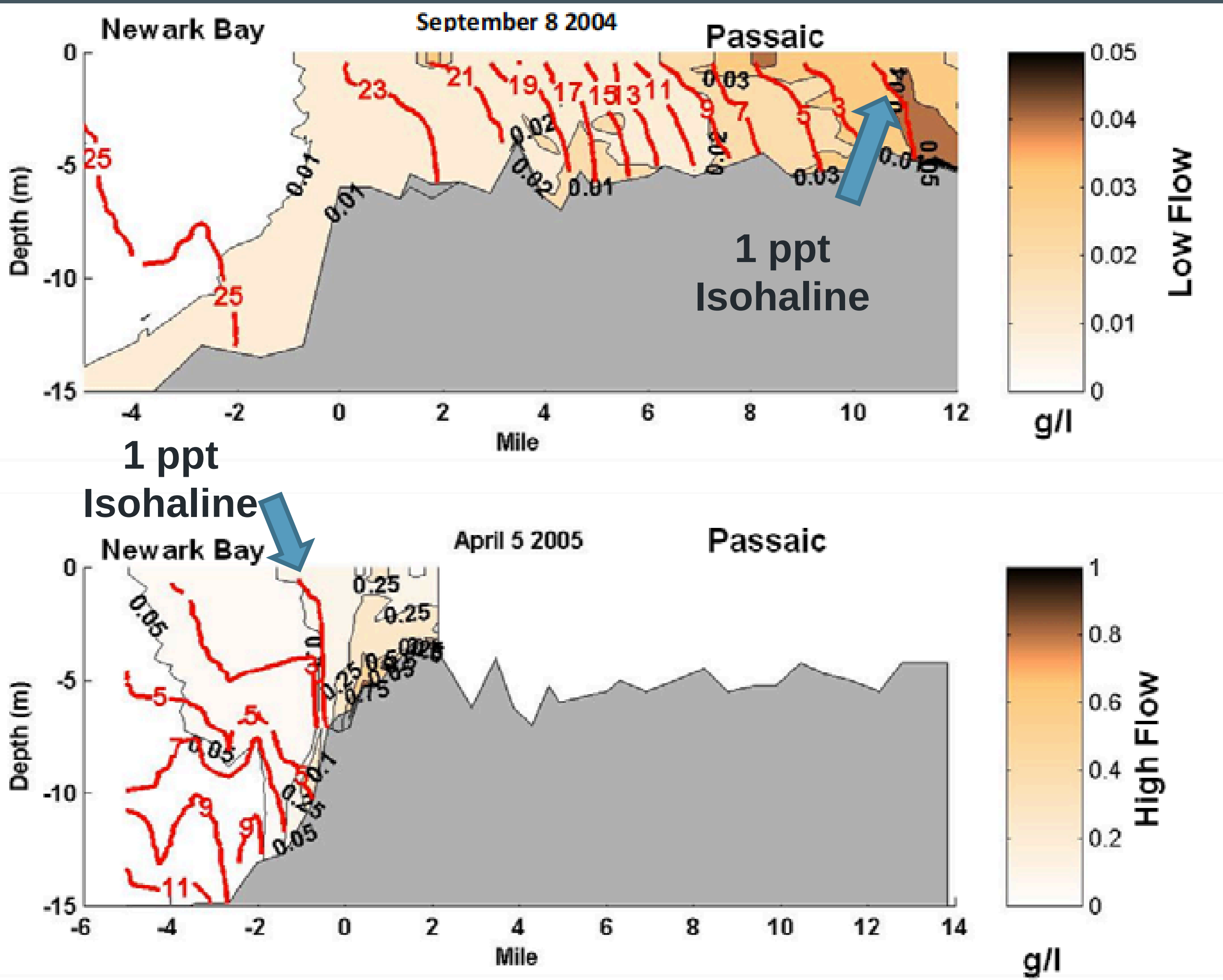
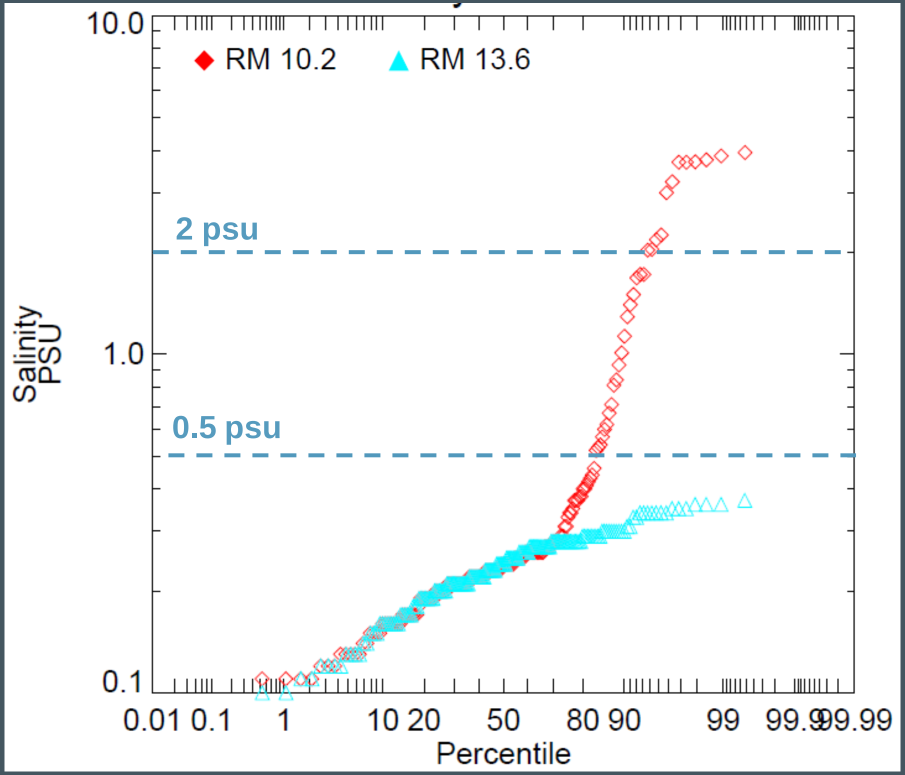


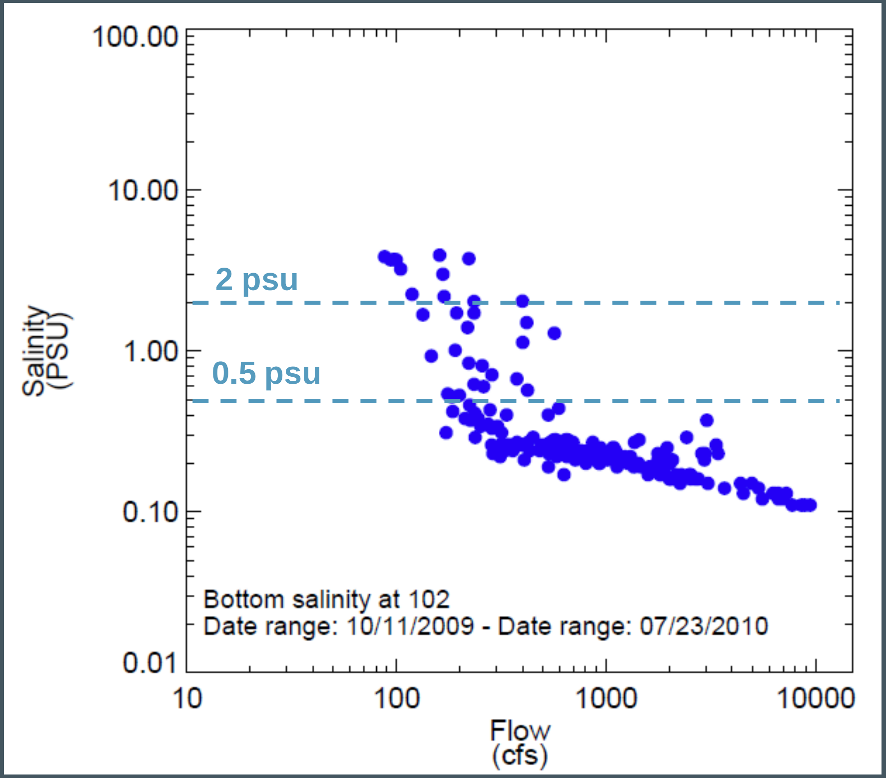
Figure 11. Longitudinal profiles of salinity and TSS from Chant (2009) corresponding to 1 and 330 m^3/s river flow rates respectively.

Salt Front Location, Recent Bathymetry: 2009/2010 Mooring Data at RM 10.2

RM 10.2 and 13.6 Max Daily Bottom Salinity



RM 10.2 Max Daily Bottom Salinity



<u>Note:</u> Flow at the Little Falls NJ USGS gage

Salt Front Location, Recent Bathymetry: Chant et al. (2010) Surveys

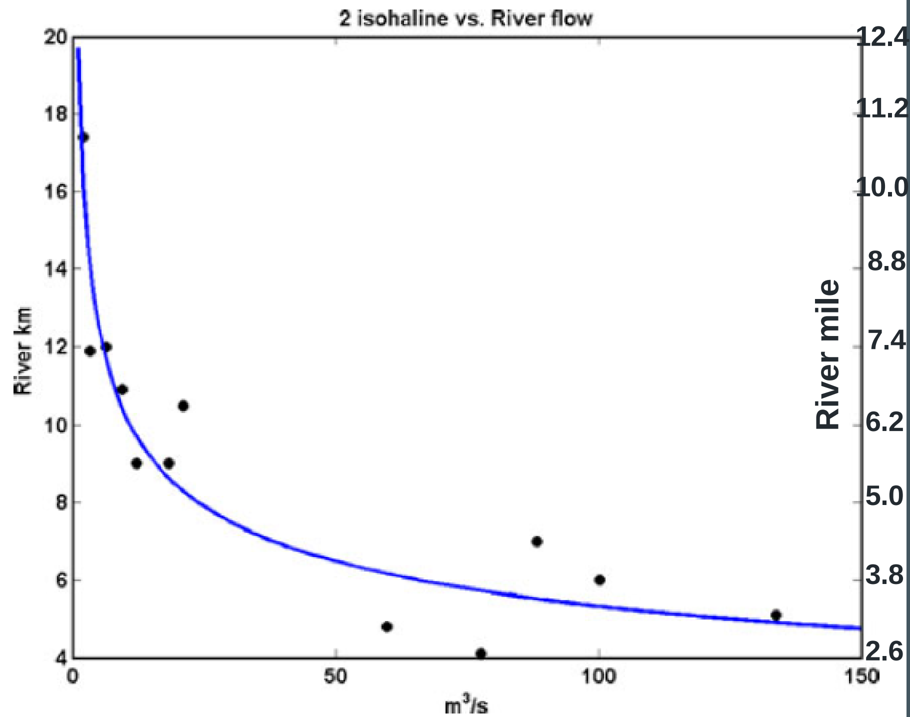
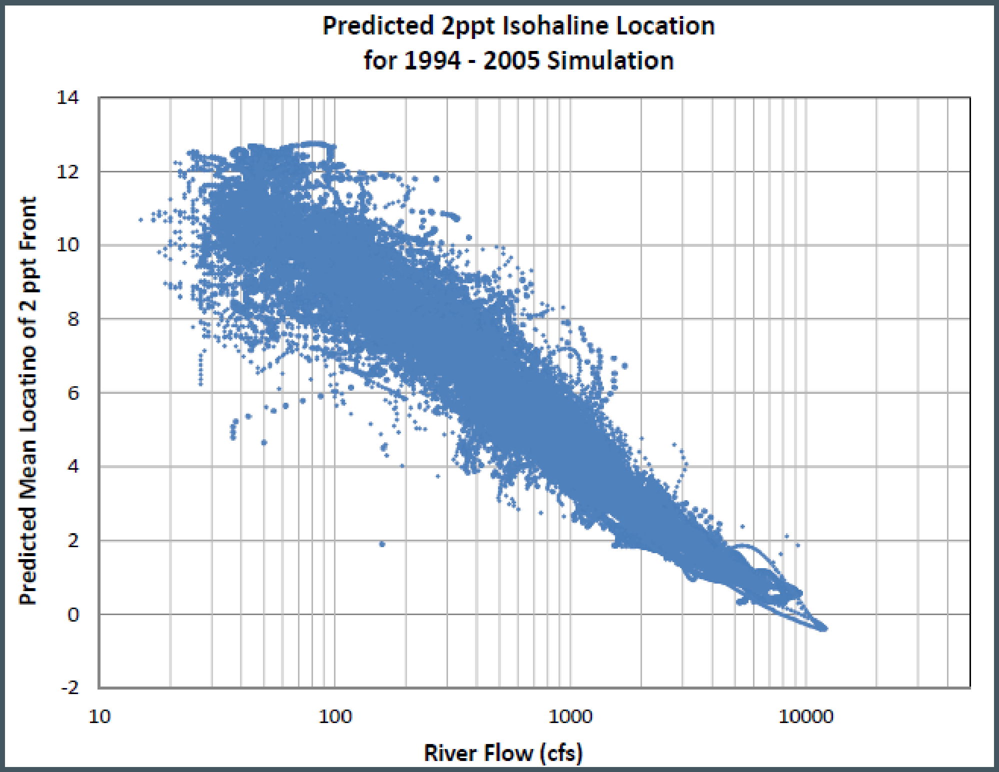


Fig. 9 Position of 2 psu isohaline based on CTD surveys of the river. Note that the surveys were all began approximately 2 h after high water because of navigational needs associated with low bridges around km 7. The *blue line* is the best fit based on river discharge which was proportional to $Q^{-0.28}$

Chant et al. (2010)

- Developed relationship for 2 ppt isohaline vs flow
- Shipboard surveys started about 2 hours after high tide
- Chant et al. (2010) observed 2 ppt near RM 10.9

Salt Front Location, Recent Bathymetry: CPG Model Results



- Simulated the 1995 to 2004 period
- Characterized the <u>**mean location of 2 ppt isohaline**</u> as a function of the flow at Little Falls NJ
- 2 ppt located at or above RM 10.9 for about 4.5% of results plotted here

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Salt Front Location, Recent Bathymetry: HQI/EPA Model Results

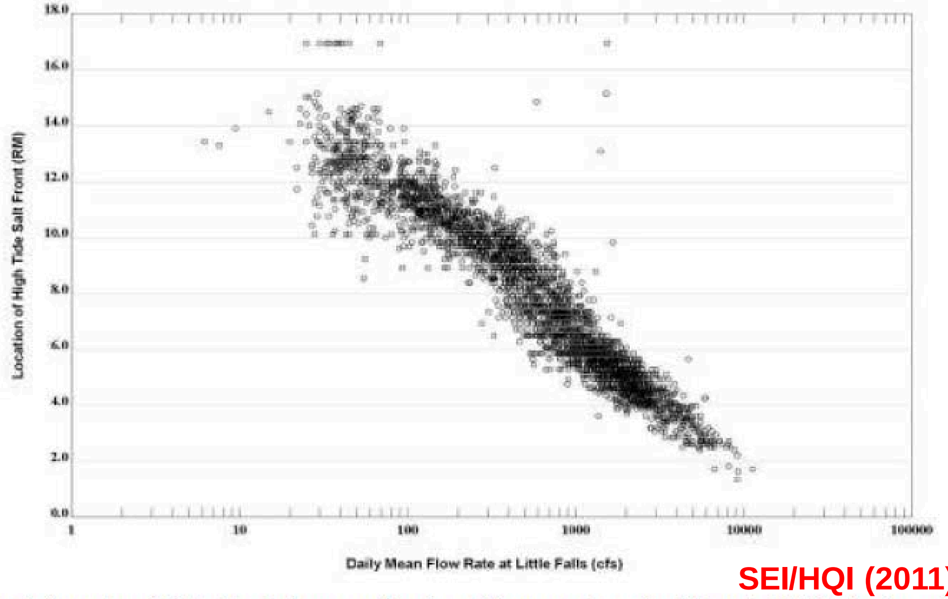

Figure 9. Location of high tide salt front as a function of flow rate determined from the HQI hydrodynamic model

- Slightly earlier version of the CPG model
- Same simulation period, 1994 - 2005
- Characterized the **high tide location of 0.5 ppt isohaline** as a function of the flow

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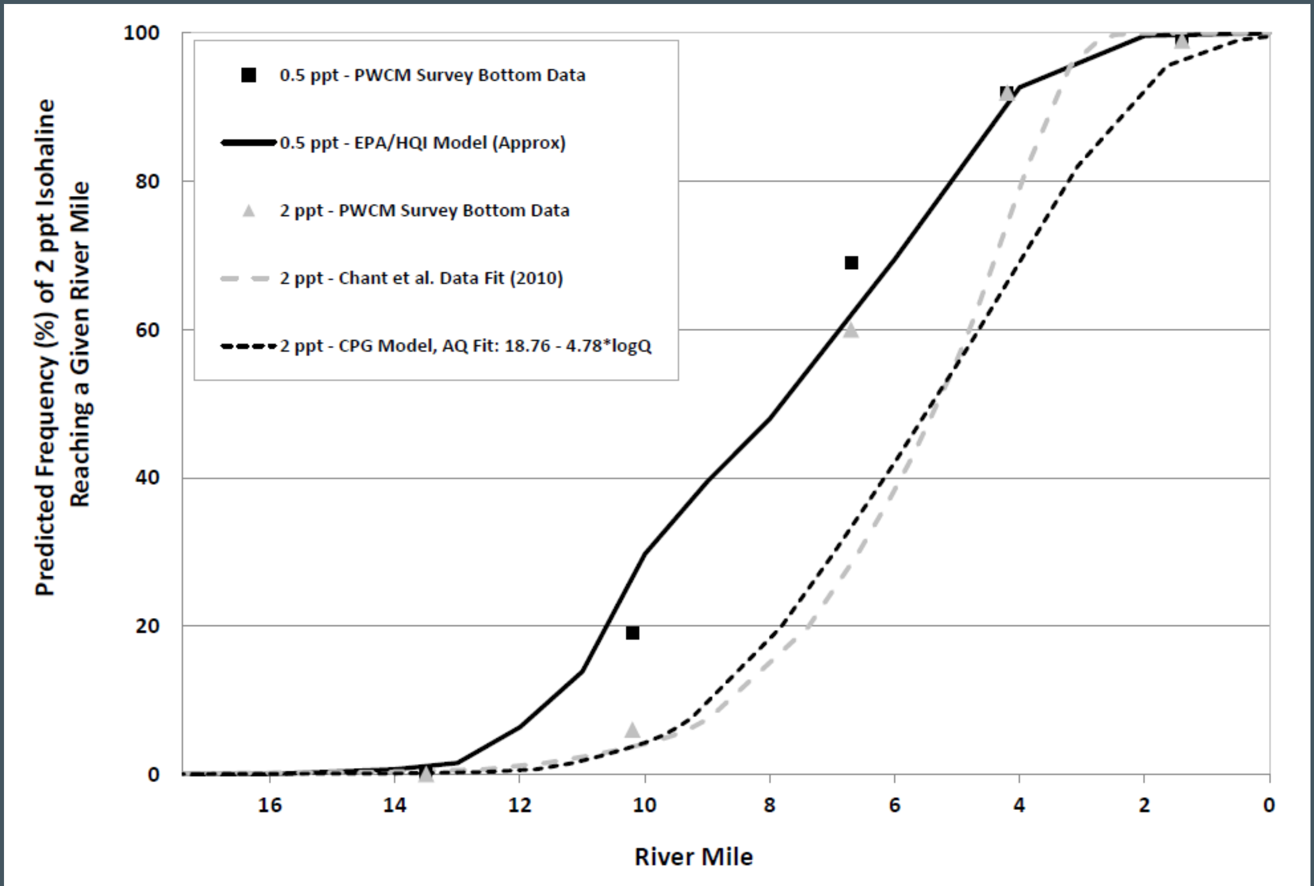
Salt Front Location, Recent Bathymetry: Predictions of Intrusion Frequency



- For PWCM data, the observed frequency of max daily bottom salinity for the sampling period is shown. For all other results, frequency was assigned using 1897 to 2011 Little Falls flow record.
- SEI/HQI (EPA) model result is approximate (read from plot) and reflects high tide location of 0.5 ppt front.
- CPG model results reflect the mean location of the 2 ppt front, using an Anchor QEA logarithmic fit.
- Chant et al. (2010) is 2+ hours after high tide, i.e., like a mean tidal position.

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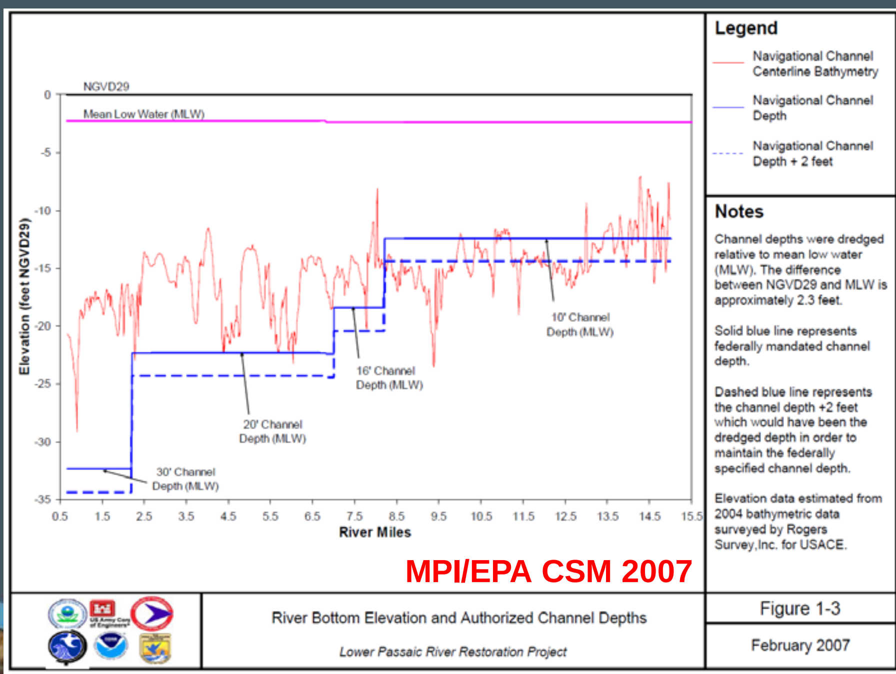
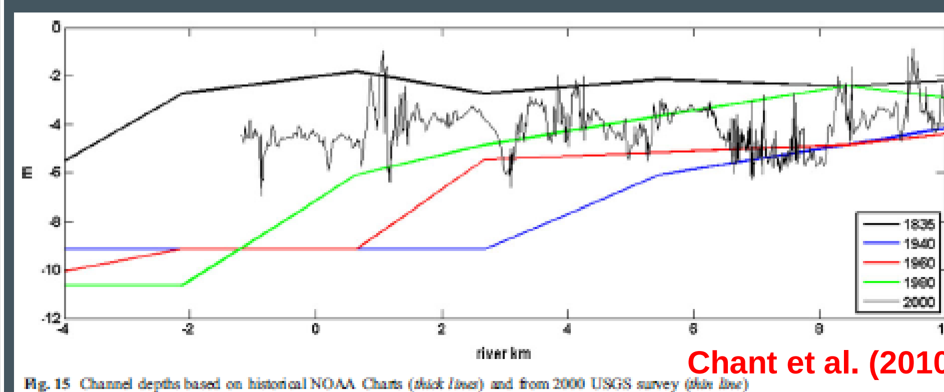
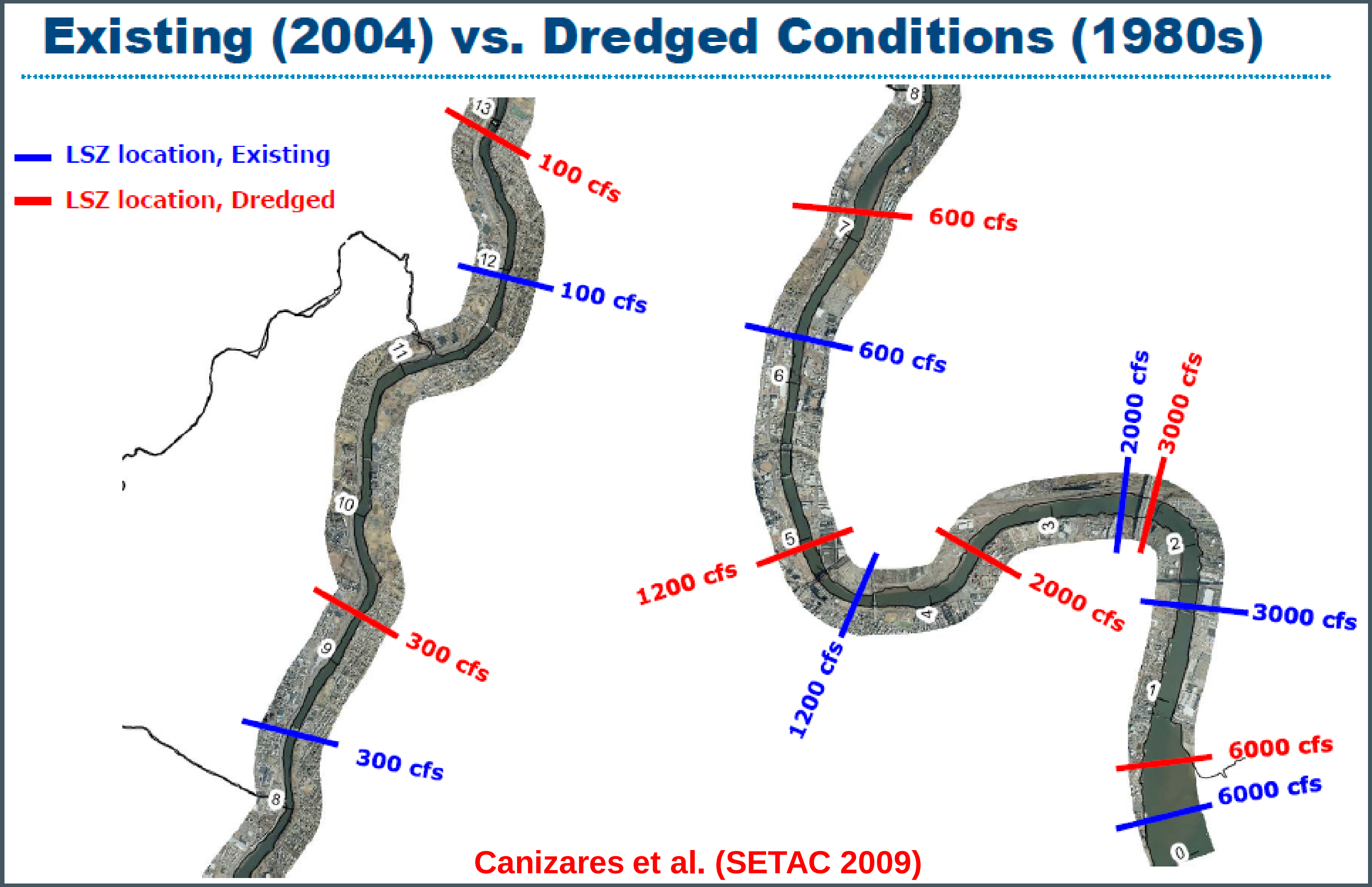
How Far Upstream Does Salt Front Reach?

- Salinity intrusion depends on river flow, tides, and geometry of the LPR and Newark Bay
- The salt front would have reached further upstream in the past when LPR was deeper (prior to infilling); see Chant et al. (2010)





Salt Front Location, Historical Bathymetry: CPG Model Sensitivity Results



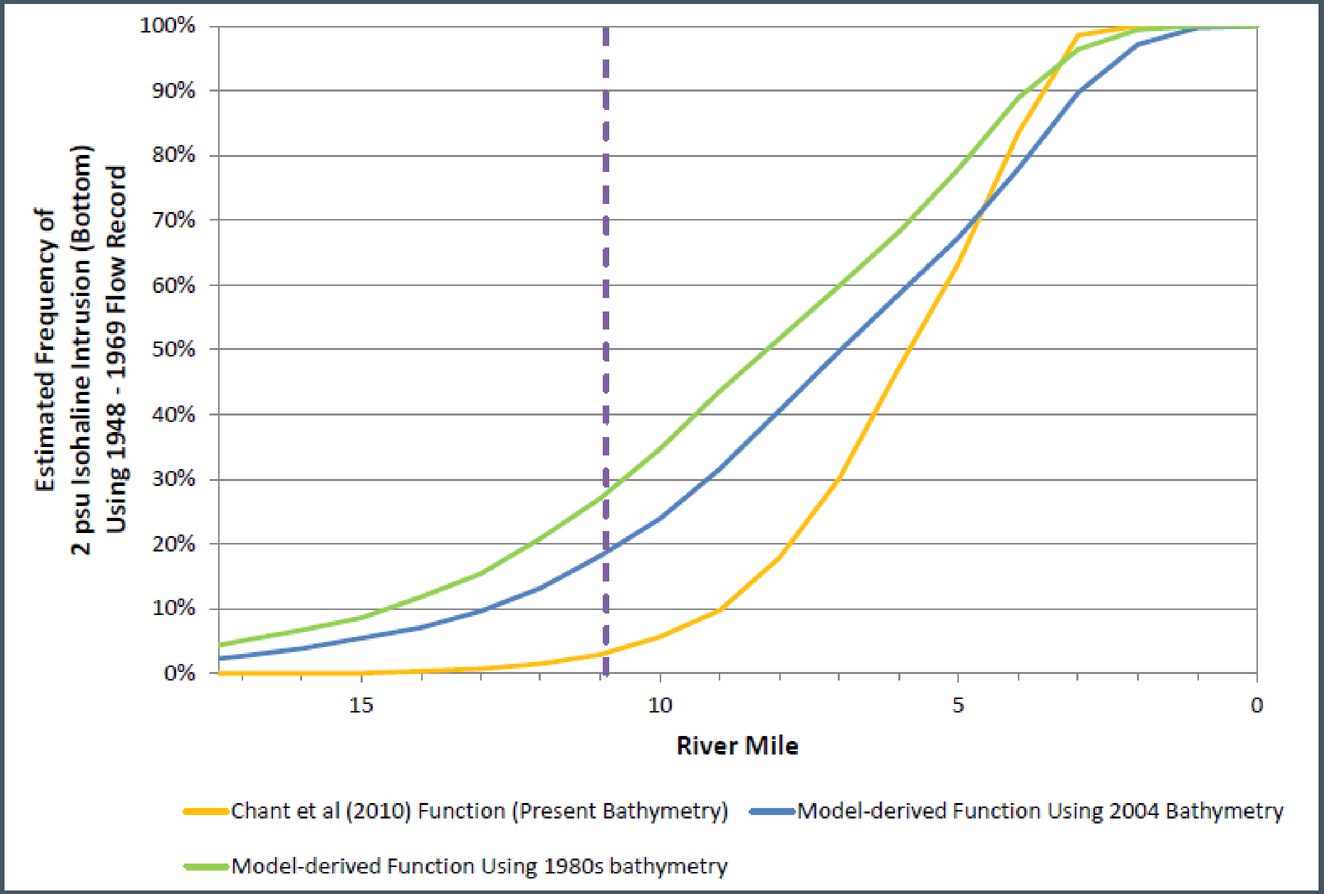
Note: LSZ = "Low Salinity Zone" = mean location of 2 ppt isohaline.

- Constant flow simulations at flows ranging from 100 to 12000 cfs, with harmonic tidal forcing

- Compare 2 ppt isohaline location for 2004 vs 1980s bathymetry

- Note difference in 2 ppt location for the 100 cfs simulation (P ≈ 7.5% in 1897 to 2011 flow record)

Salt Front Location, Bathymetry Impacts: Predictions of Bottom Salinity Intrusion



Model relationships taken from Canizares et al. (SETAC 2009), applying 1948-1969 flow frequencies. Note that a small number of cases were used to derive functions; treat qualitatively.

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Consider Low River Flows During Agent Orange Manufacturing Period

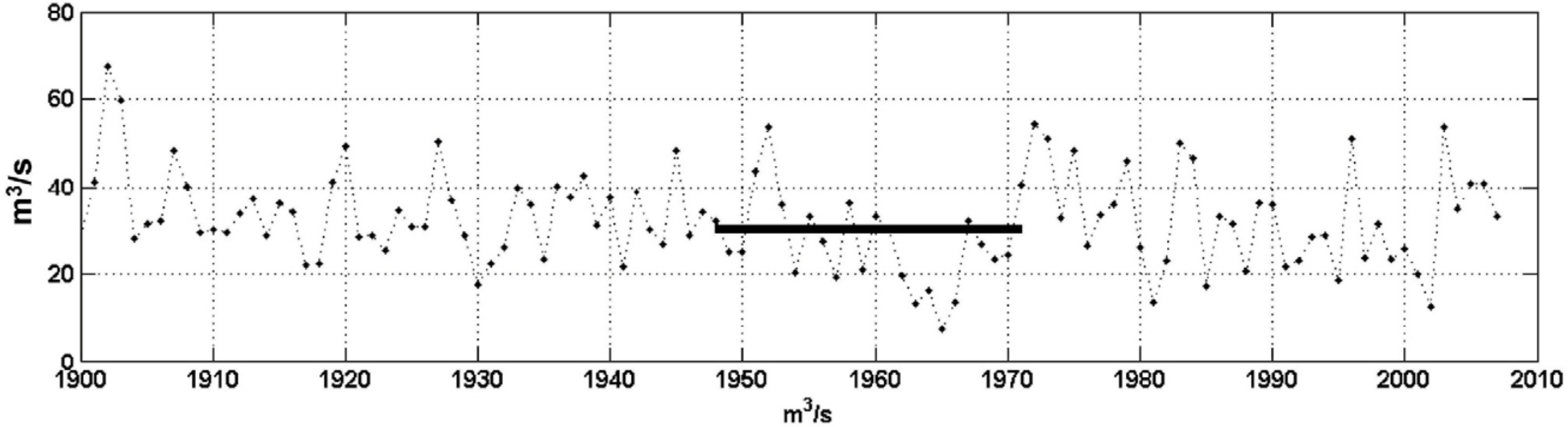


Fig. 16 Mean annual river discharge from 1900 to 2008. *Thick solid line* depicts time period that Agent Orange was manufactured along the Harrison Reach near mooring M2

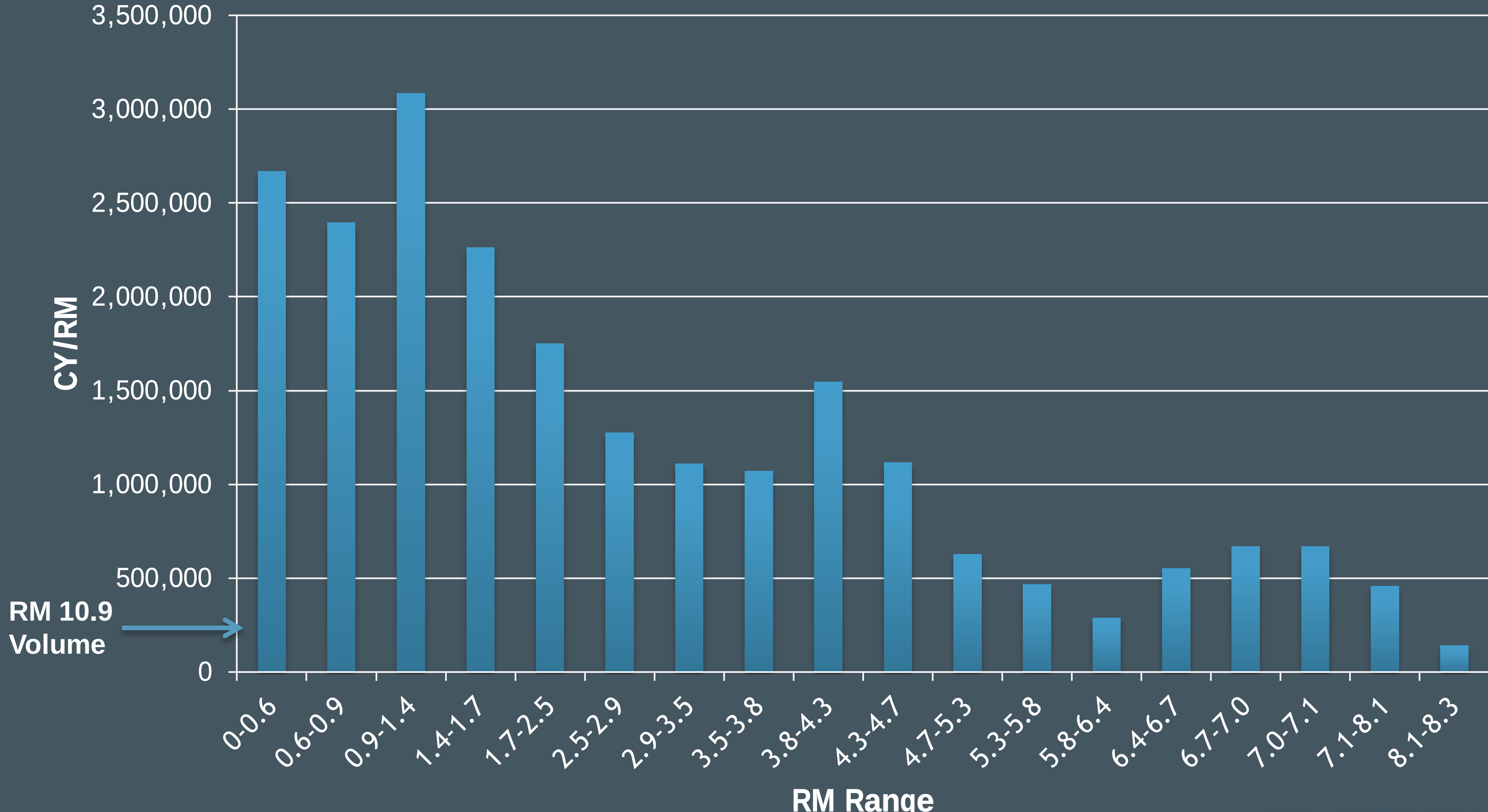
Chant et al. (2010)

Consider 1948 to 1970 Hydrograph

Day of month	10^{th} percentile of daily mean values for each day for 21 - 22 years of record in, cfs (Calculation Period 1948-10-01 -> 1970-09-30) Period-of-record for statistical calculation restricted by user											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	234	173	331	402	551	149	70	42	39	75	71	144
2	227	154	333	389	515	194	82	38	29	59	86	139
3	248	133	334	373	544	197	75	41	31	78	95	140
4	214	150	378	325	481	187	80	41	30	73	91	156
5	228	133	394	297	416	162	95	42	54	74	87	168
6	236	158	434	306	379	189	88	38	39	62	79	164
7	234	212	451	347	348	155	71	37	44	88	62	163
8	231	283	465	355	366	166	80	38	36	85	79	150
9	241	264	510	374	355	155	84	42	36	89	84	148
10	262	283	500	342	326	146	102	33	37	79	100	143
11	241	236	500	335	321	145	66	40	37	75	70	116
12	201	305	479	305	289	139	83	40	27	71	91	136
13	249	290	471	295	262	127	71	64	28	65	64	311
14	252	333	525	299	243	128	69	49	38	67	96	375
15	226	301	620	277	245	134	59	40	51	53	109	351
16	176	305	671	279	224	126	61	51	75	57	108	294
17	160	342	721	276	231	104	44	51	78	59	106	271
18	200	326	738	293	220	94	42	42	57	64	124	244
19	174	315	692	302	214	90	66	35	52	69	134	234
20	158	333	655	281	195	83	61	48	44	76	110	228
21	189	339	584	248	179	93	54	31	51	60	153	198
22	192	317	544	245	152	80	32	38	46	63	120	181
23	244	289	544	291	181	66	40	33	45	61	104	170
24	224	335	519	314	199	59	36	42	40	58	101	164
25	240	307	668	324	196	62	38	46	52	58	121	185
26	223	301	624	403	187	85	29	42	35	75	156	222
27	228	274	656	443	165	42	33	30	46	77	148	225
28	230	289	563	464	161	44	32	37	52	73	159	238
29	229		539	408	158	69	33	37	45	87	186	272
30	182		464	374	159	60	31	36	68	65	183	246
31	181		426		143		50	36		63		224

RM 10.9 Contaminated Sediment Volume Consistent With Spatial Pattern in River

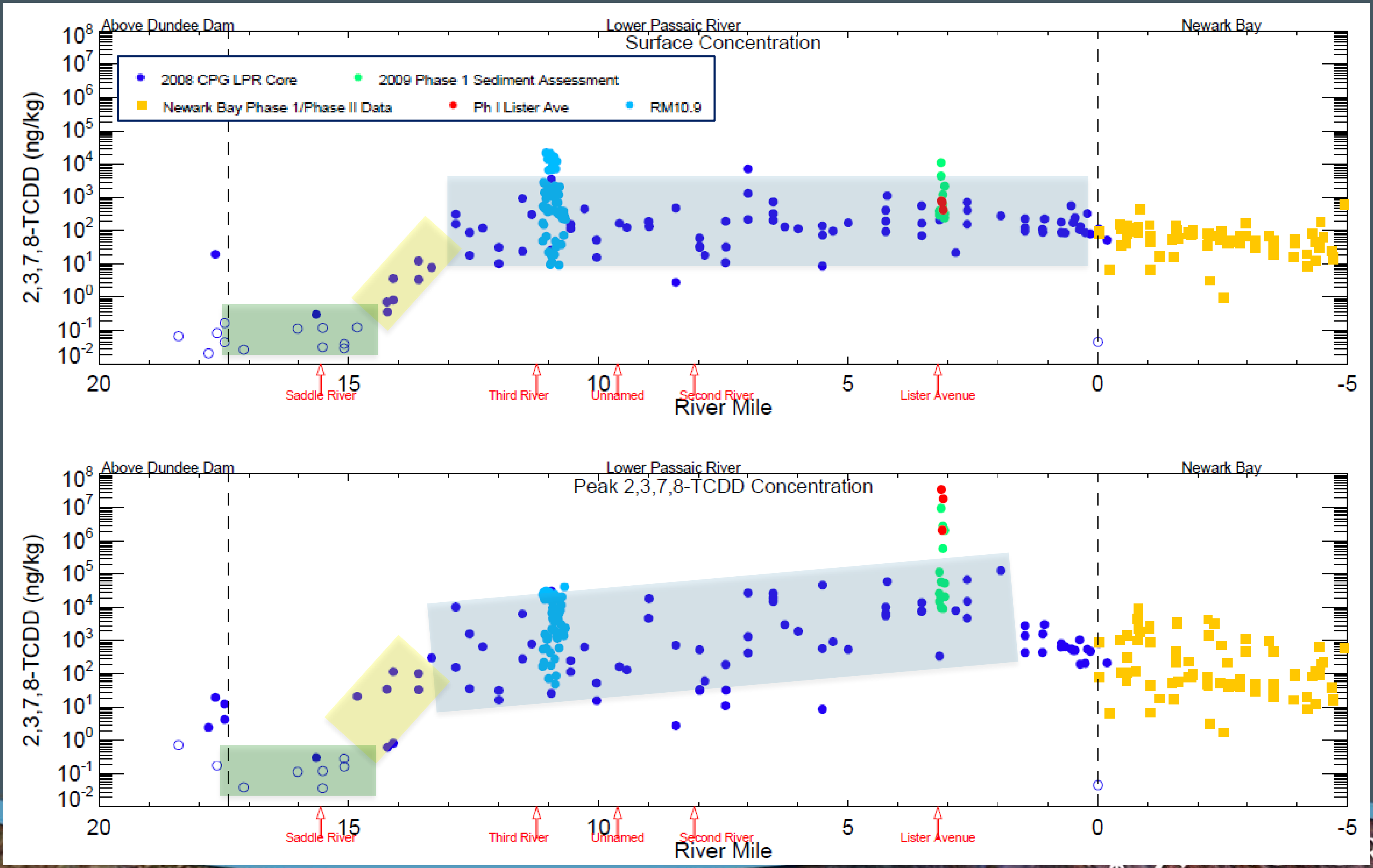
Reflecting dredging and estuarine dynamics, including channel geomorphology and ETM movement



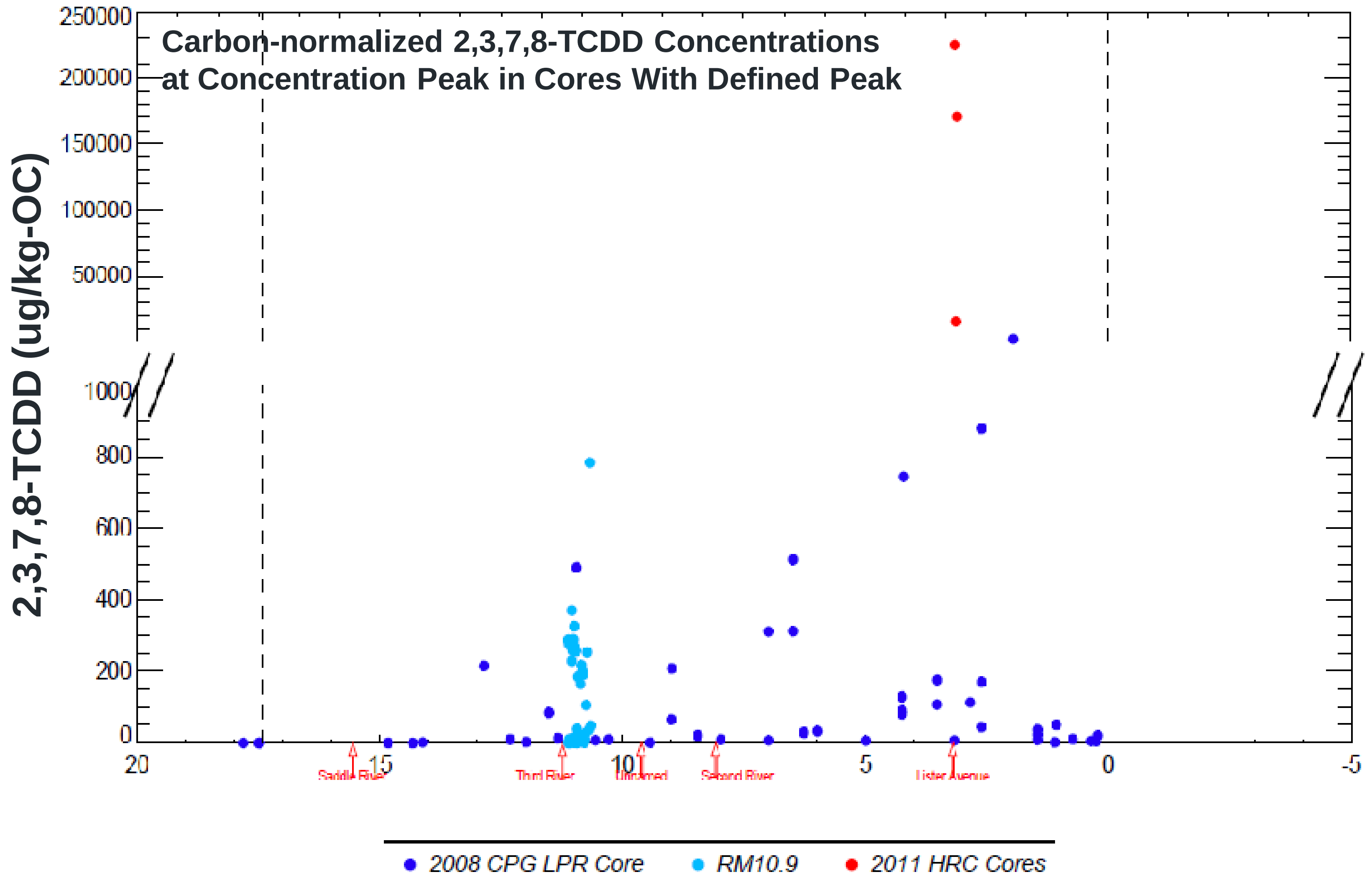
From FFS Appendix I, Table 4

2,3,7,8-TCDD PATTERNS

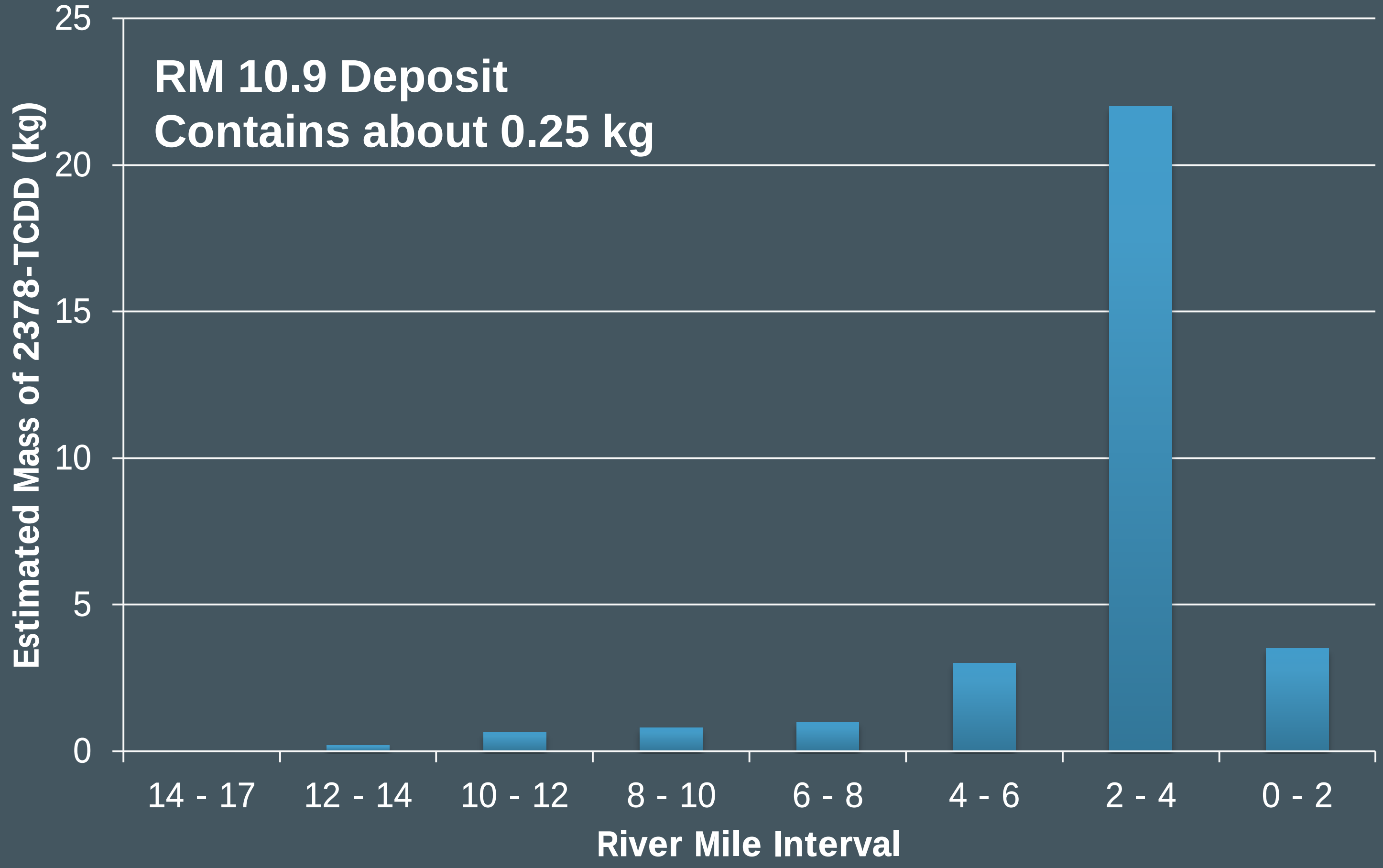
2,3,7,8-TCDD Extends to RM 13



Peak Sediment 2,3,7,8-TCDD Concentrations at RM 10.9 Are Consistent With the Overall Spatial Pattern



Spatial Pattern of 2,3,7,8-TCDD Mass Shows Evidence of Only One Source

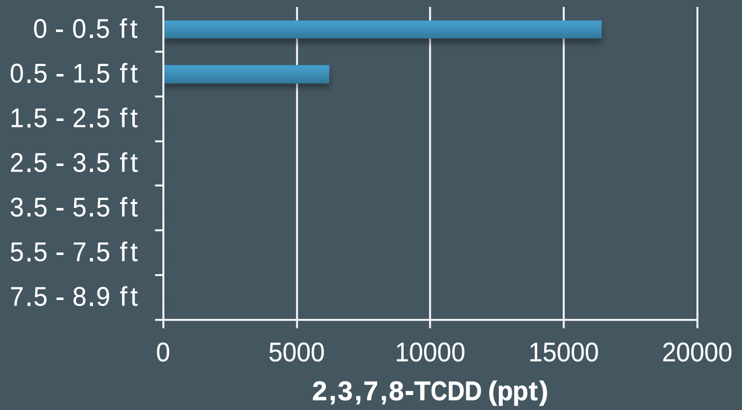


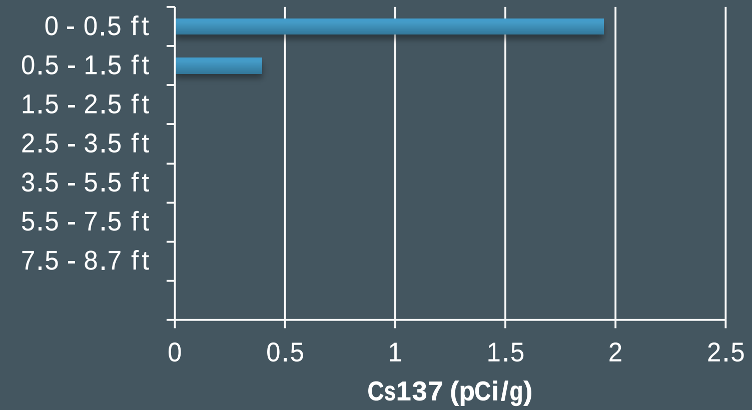
Note: mass estimates subject to refinement based on supplemental sampling data and interpolation method

RM 10.9 Peak TCDD Laid Down Circa 1960

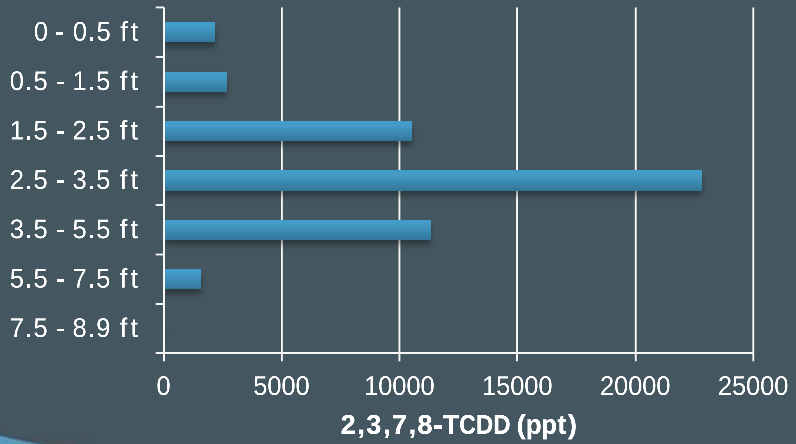
Based on correspondence of peak Cs137 and 2,3,7,8-TCDD

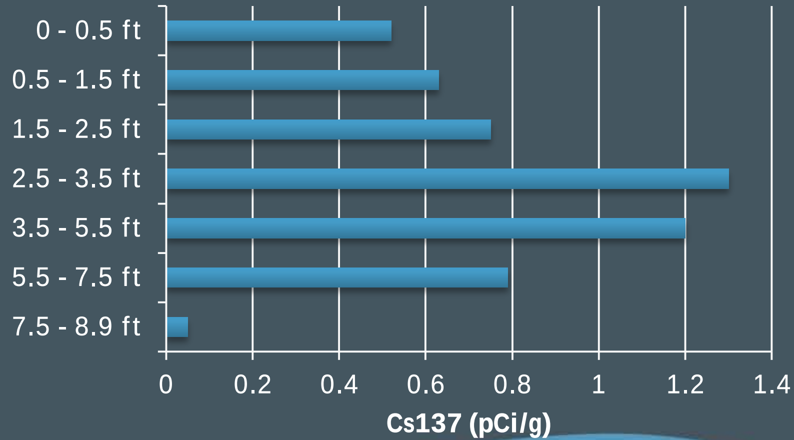
Core 331





Core 322





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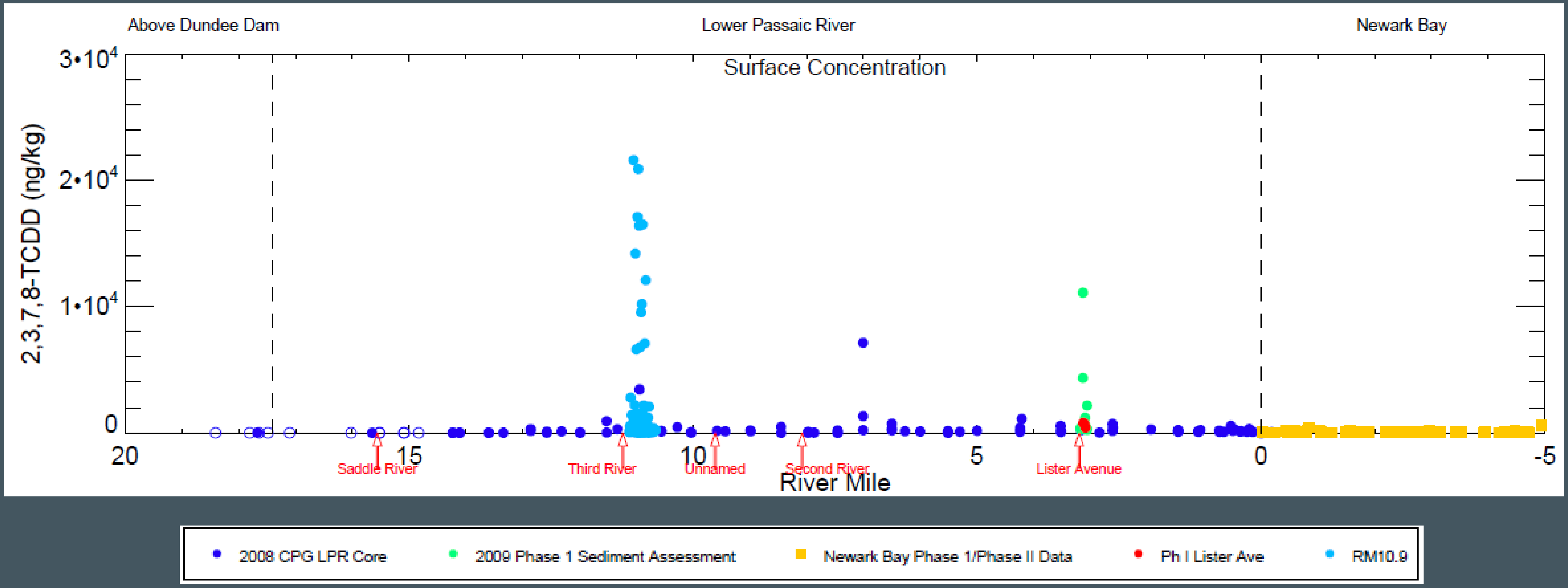
A Number of the RM 10.9 Surface Sediment Samples Have High 2378-TCDD Due to Lack of Burial



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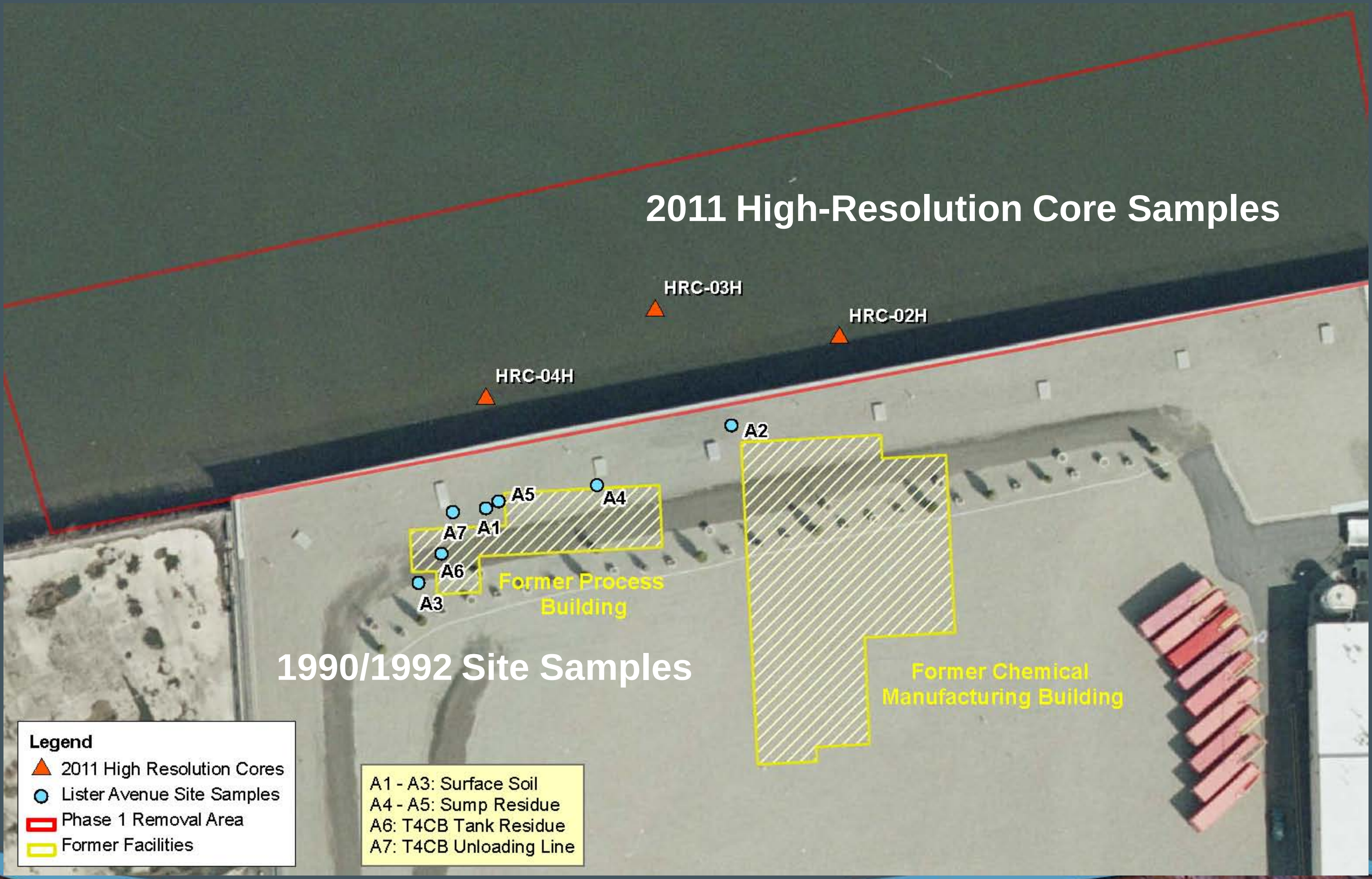
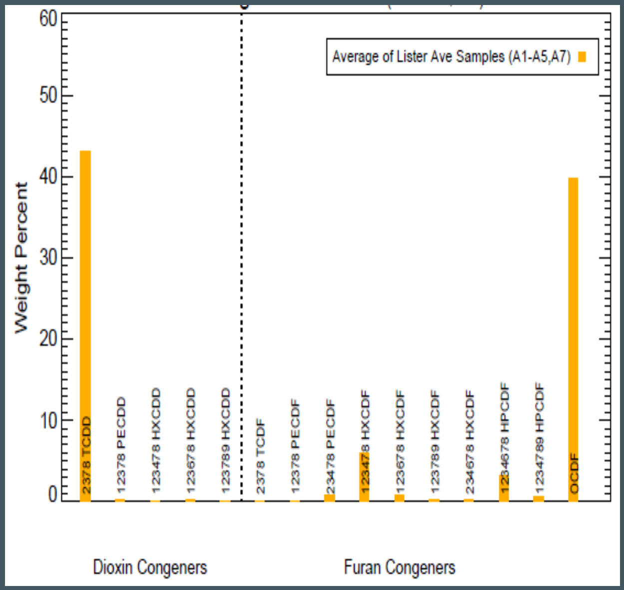
FINGERPRINTING EVIDENCE

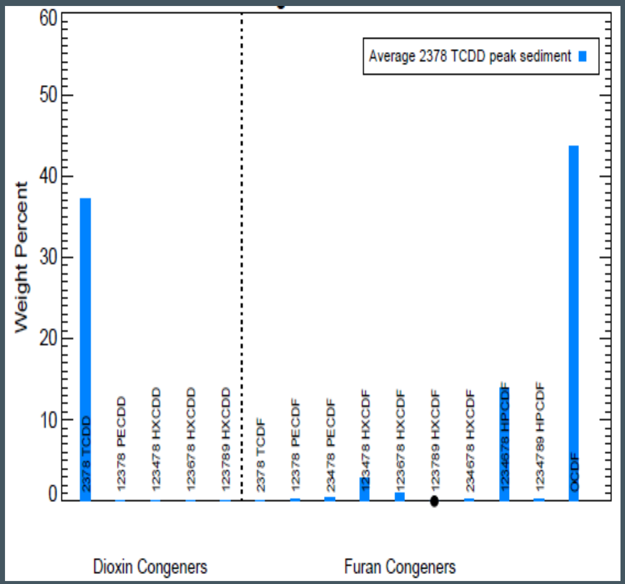
Site and LPR HRC Sampling Locations



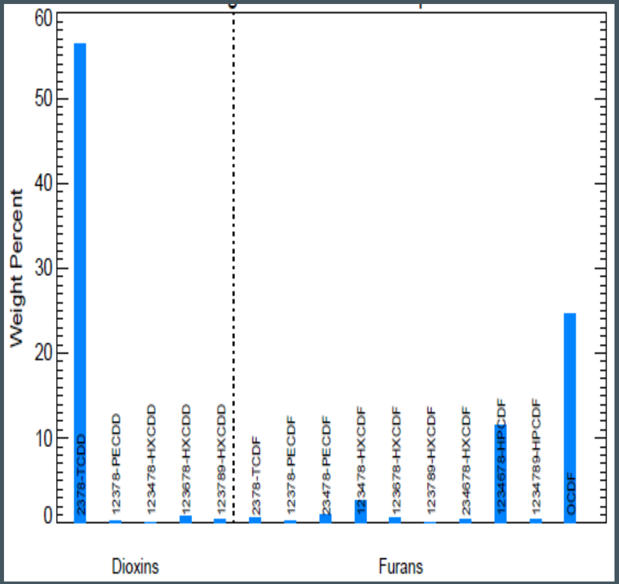
Average Dioxin/Furan Fingerprint



Lister Avenue Site Samples (excluding Tank Residue sample)



Tierra Phase 1 Sediment at Peak 2,3,7,8-TCDD



RM 10.9 Core Samples At Peak 2,3,7,8-TCDD

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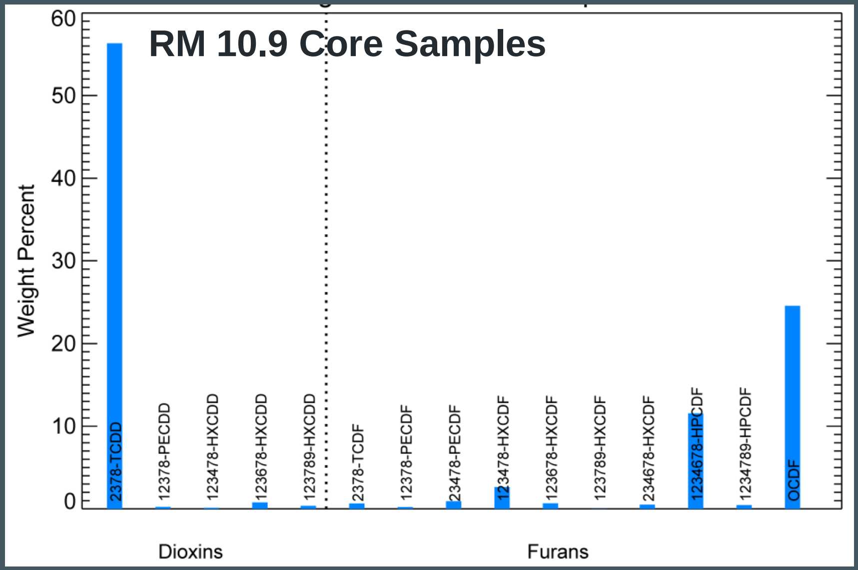
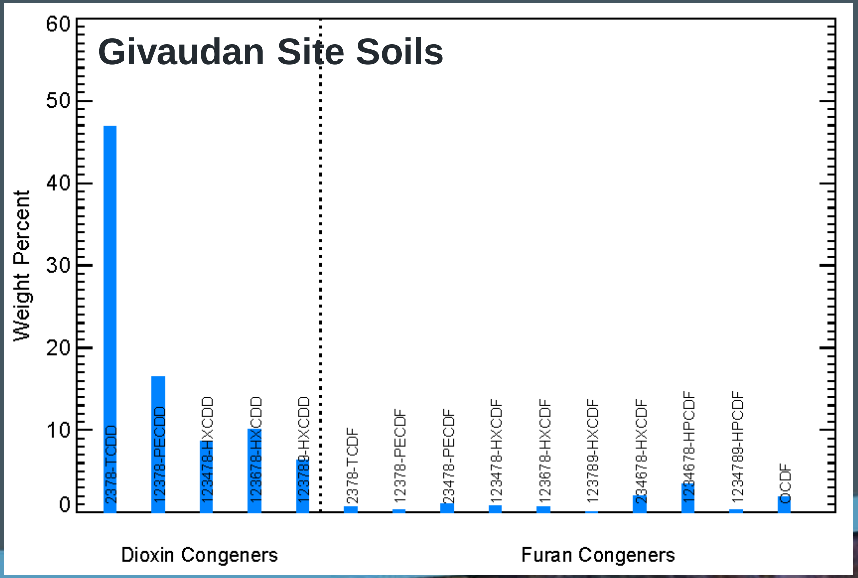
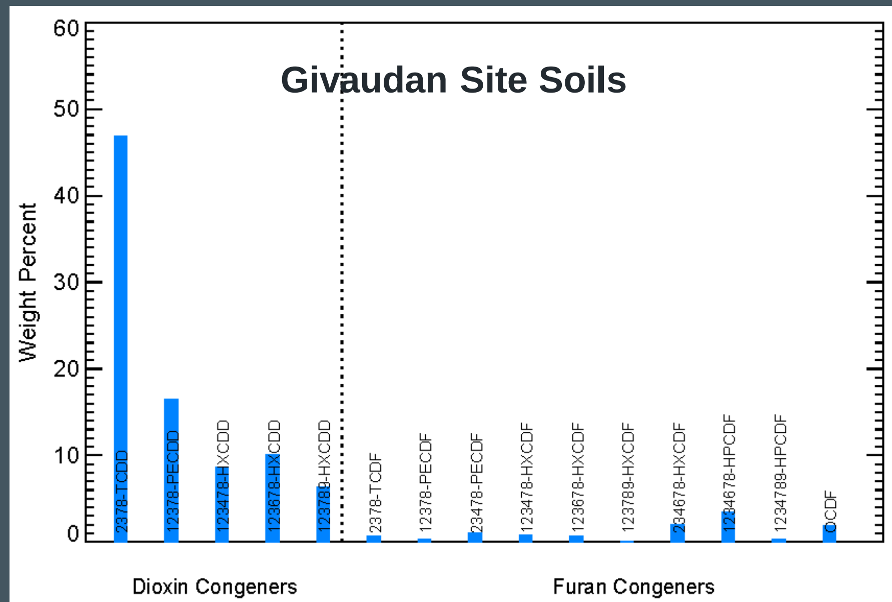
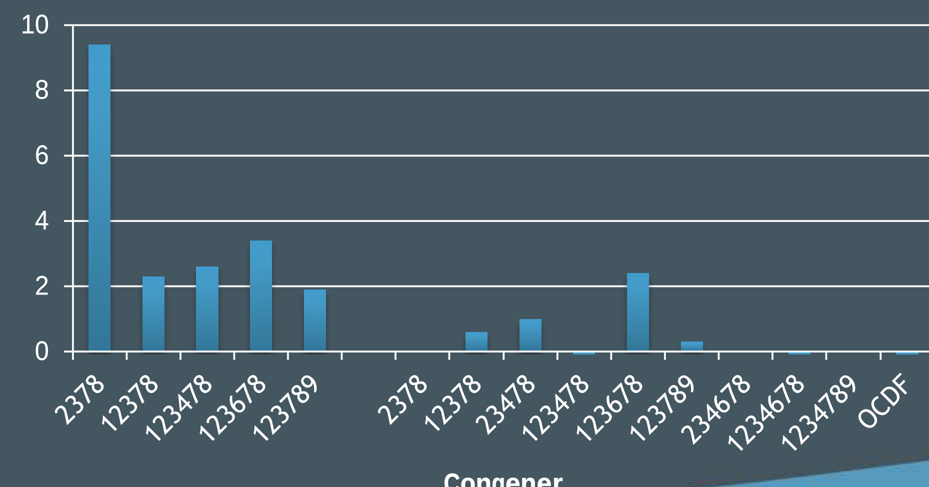
Comparison of RM 10.9 and Givaudan Site Fingerprints





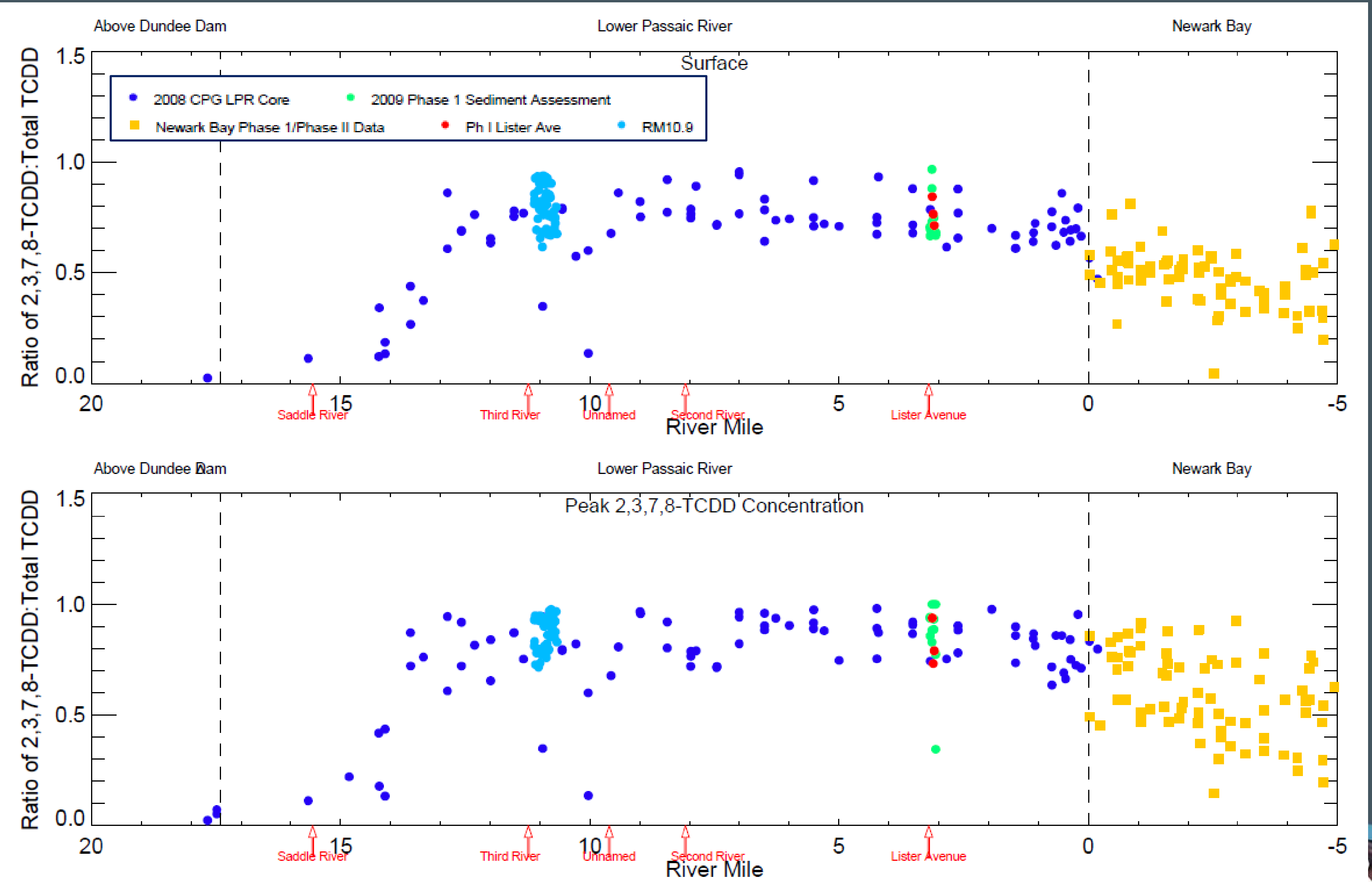
Givaudan Fingerprint Confirmed By Fingerprint in 245-TCP Workers



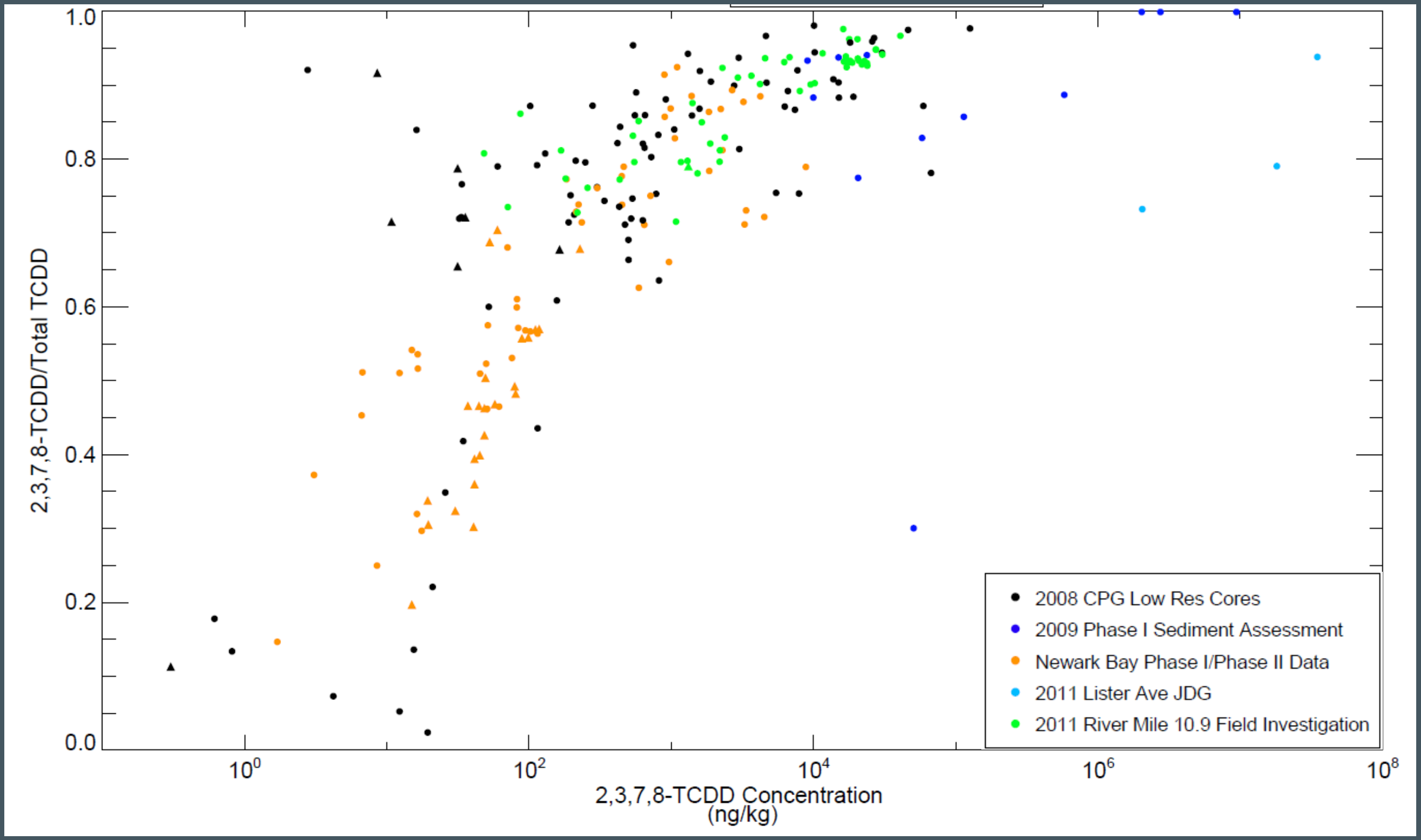


Excess Dioxin/furan in blood of 245-TCP workers
Dow Chemical

2378/Total TCDD Signature at RM 10.9 Consistent With Downstream Sediments

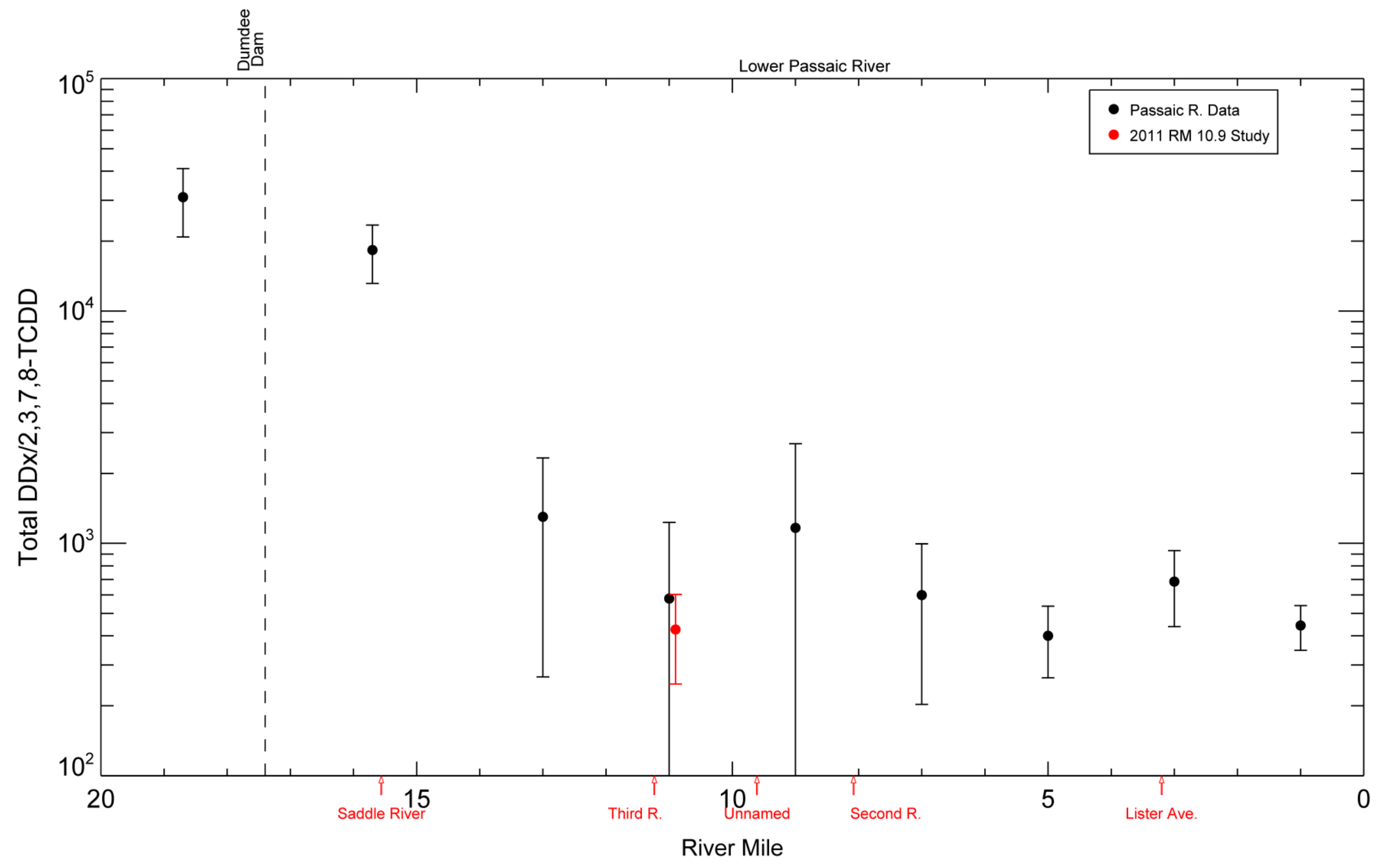


2378/Total TCDD Signature at RM 10.9 Consistent With Downstream Sediments



Ratio at the depth of local maximum 2,3,7,8-TCDD concentration

Total DDx to 2,3,7,8-TCDD Ratio Similar to Downstream Sediments



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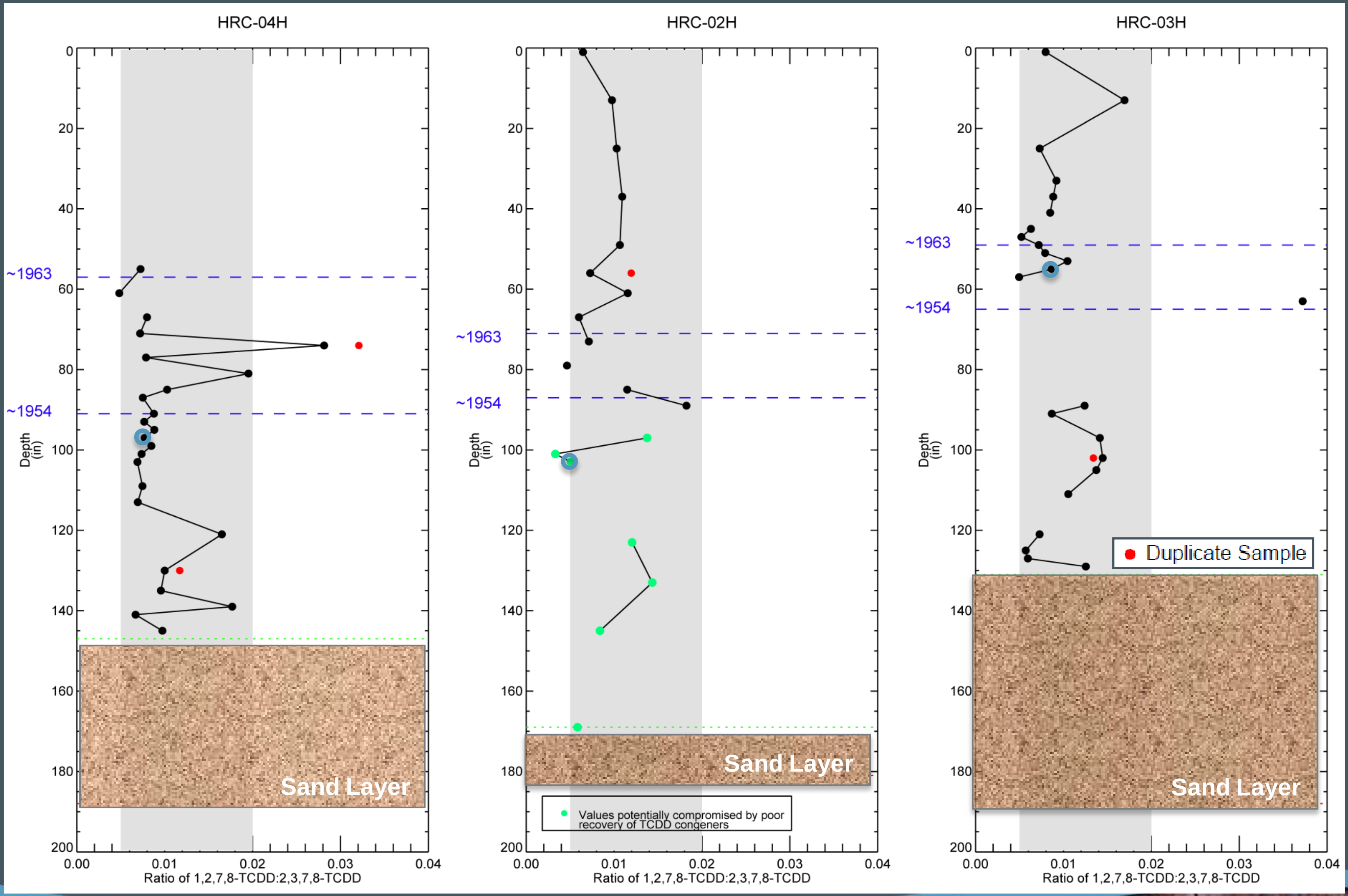
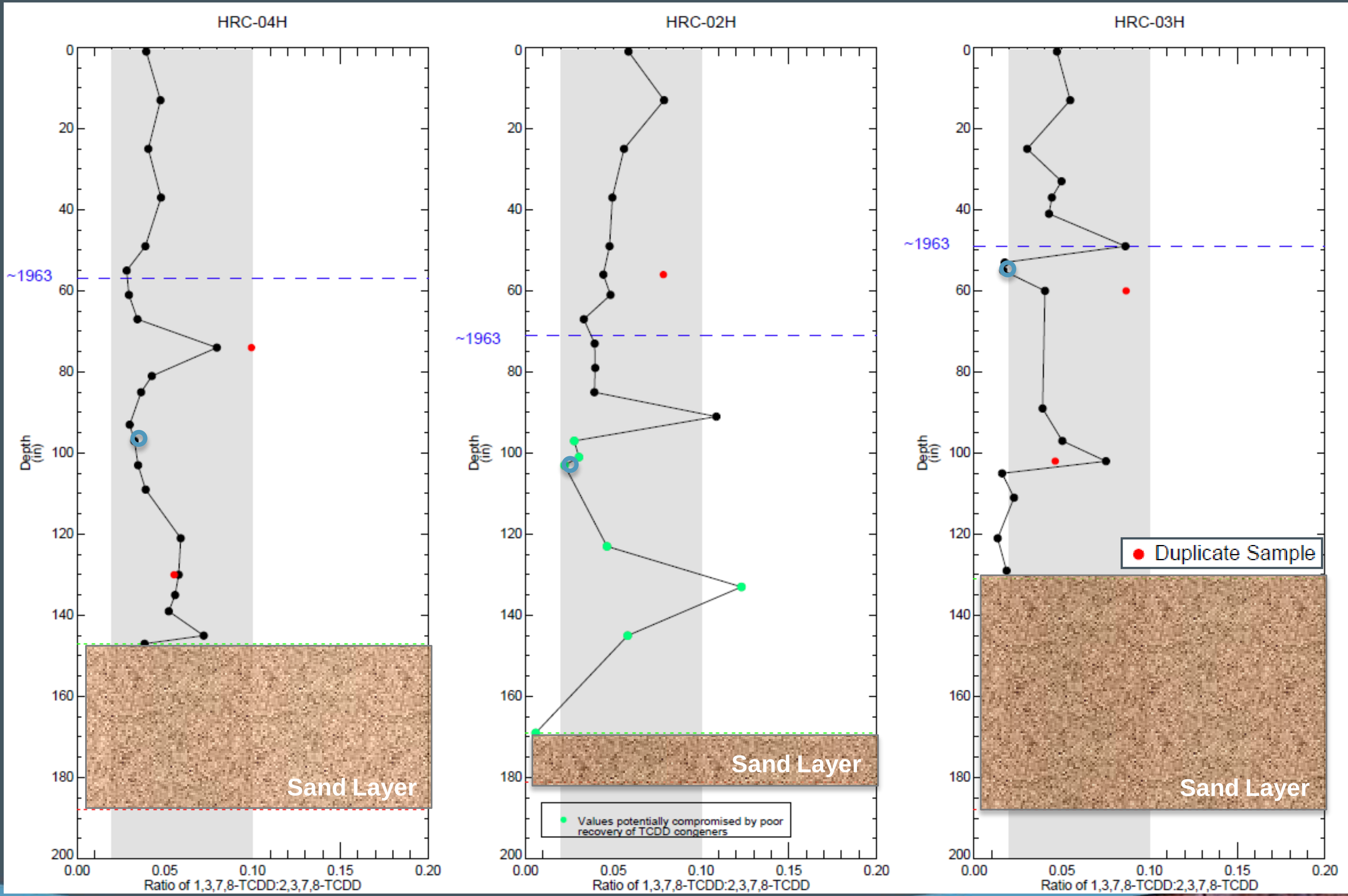
Additional Lister Avenue Fingerprints - 1,2,7,8-TCDD to 2,3,7,8-TCDD



Location of peak 2,3,7,8-TCDD concentration

Additional Lister Avenue Fingerprints - 1,3,7,8-TCDD to 2,3,7,8-TCDD



Location of peak 2,3,7,8-TCDD concentration

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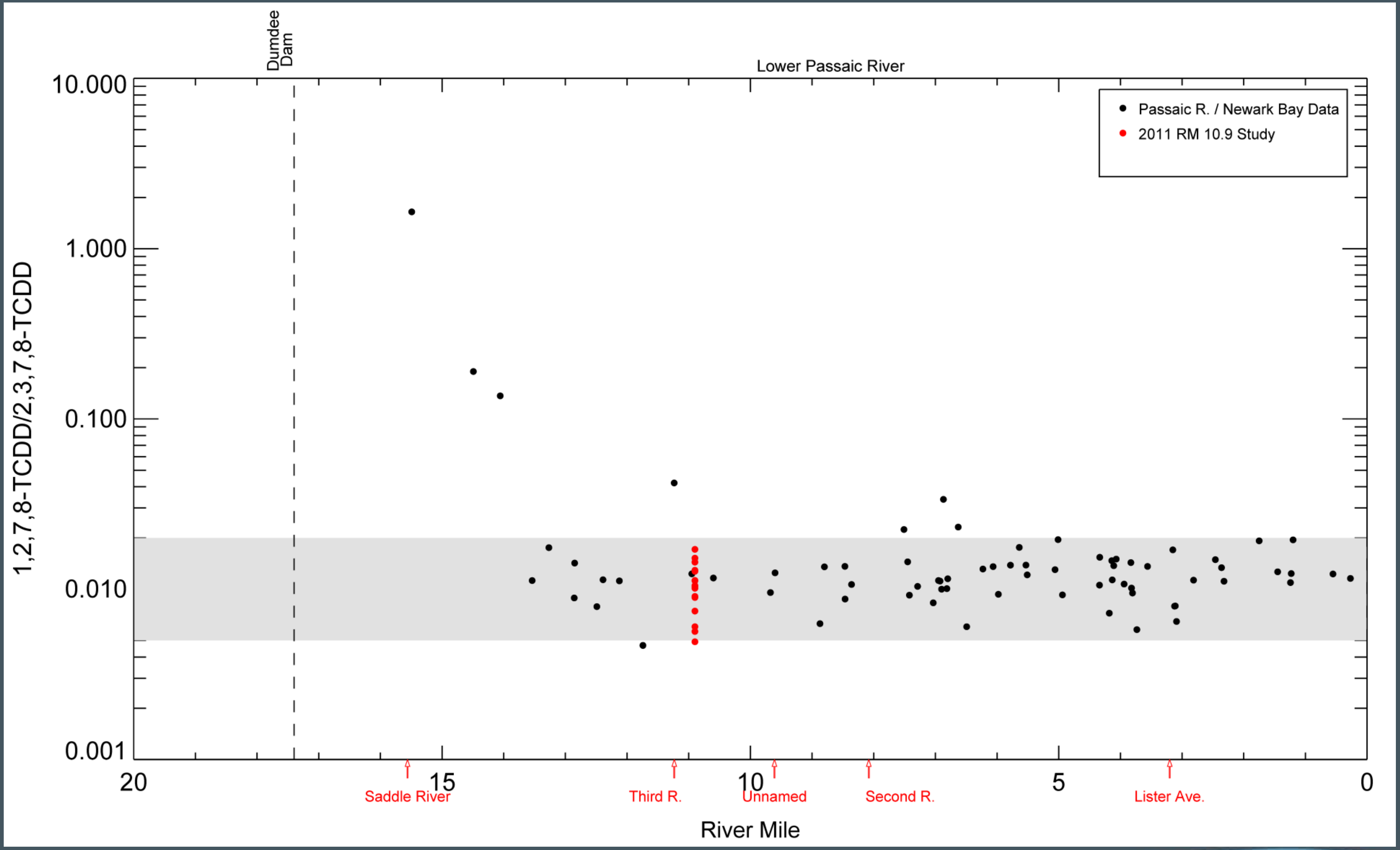
1,2,7,8-TCDD to 2,3,7,8-TCDD Ratio at RM 10.9 Matches Downstream & Lister Ave.



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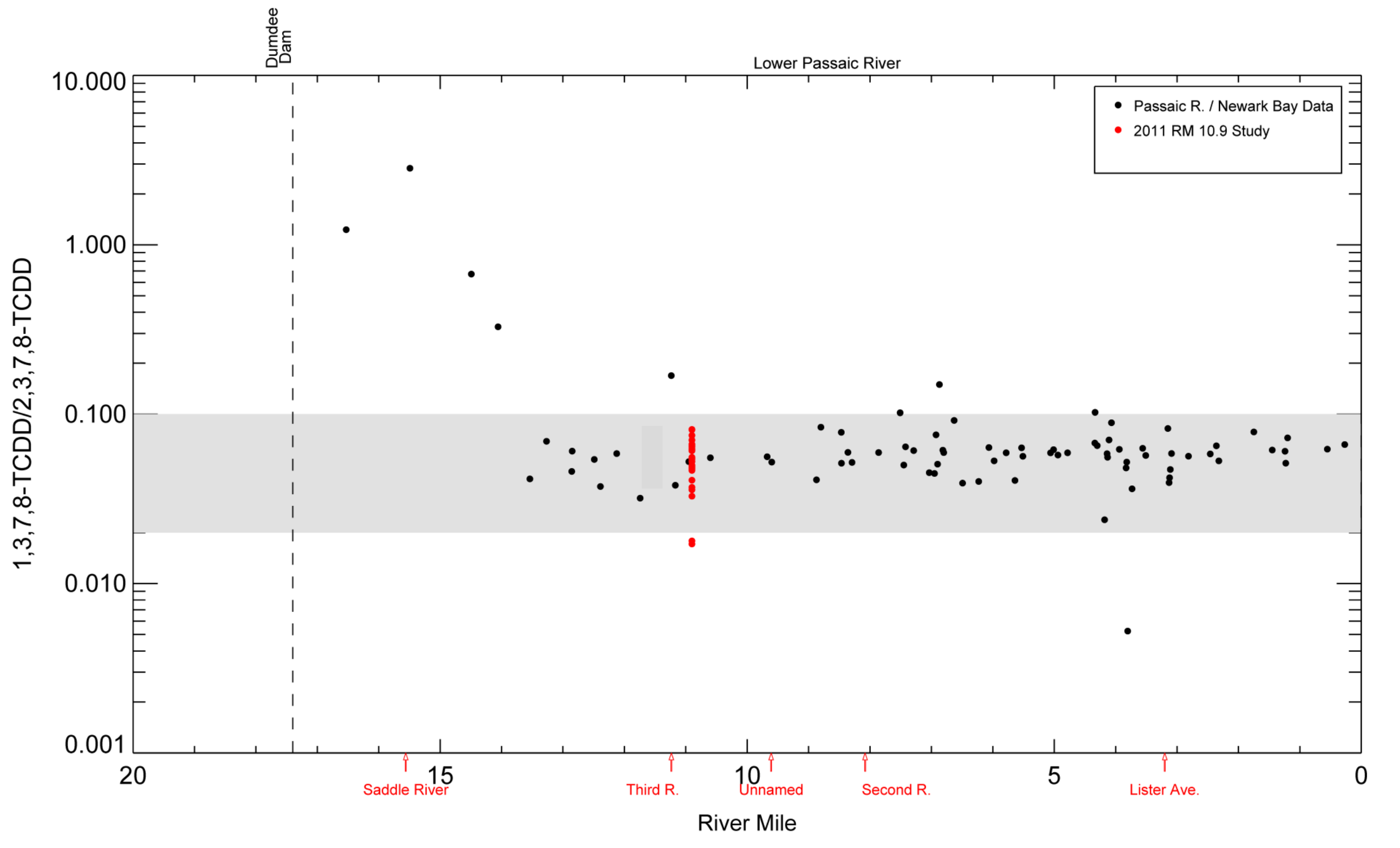
1,3,7,8-TCDD to 2,3,7,8-TCDD Ratio at RM 10.9 Matches Downstream & Lister Ave.



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Tierra 2011 Sediment Study – HCX Concentrations

- Concentrations at RM 11.5 suggest considerable dilution of HCX at RM 10.9, meaning that the concentrations reaching the 10.9 deposit were much lower
- No comparison made of concentrations at RM 10.9 and expected background HCX concentrations

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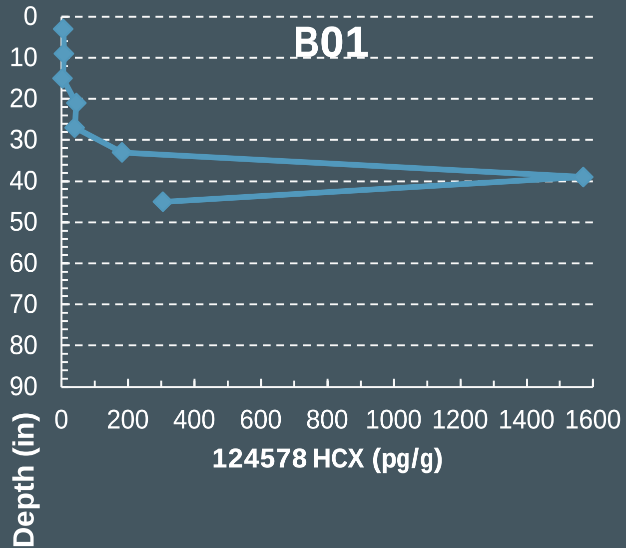
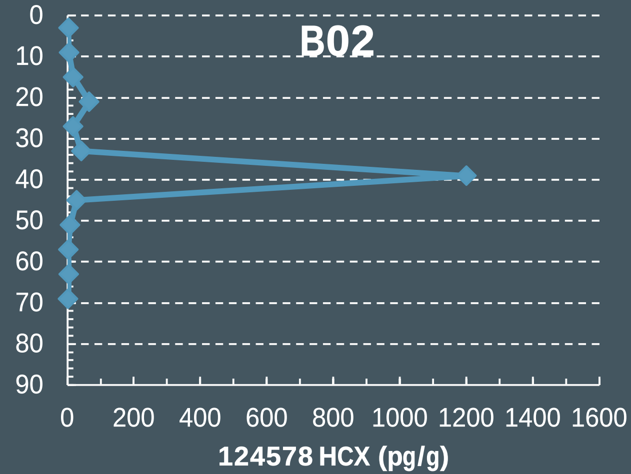
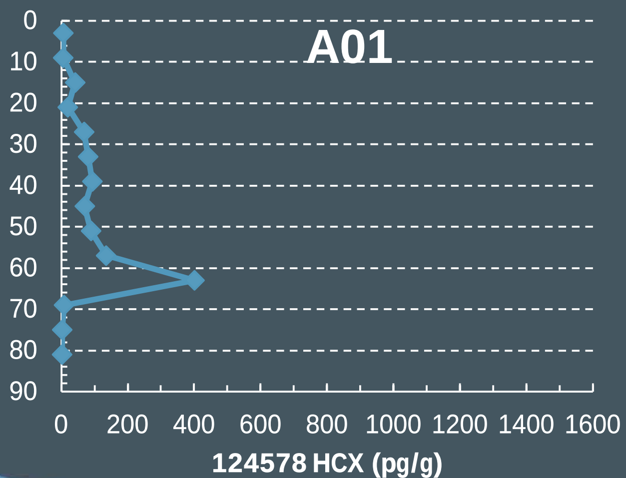
HCX Much Lower at RM 10.9 than at RM 11.5

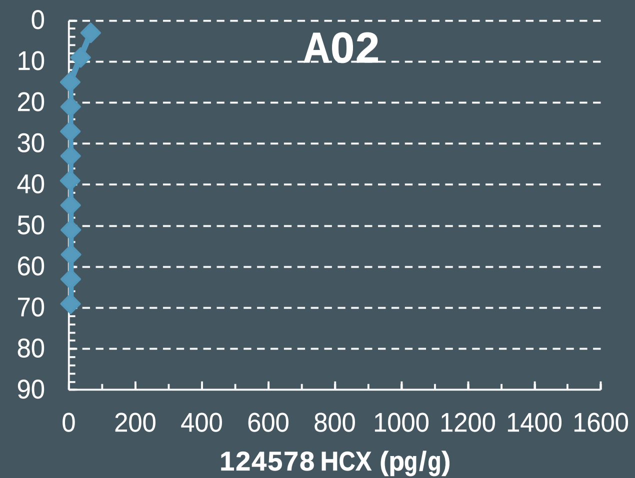
RM 11.5

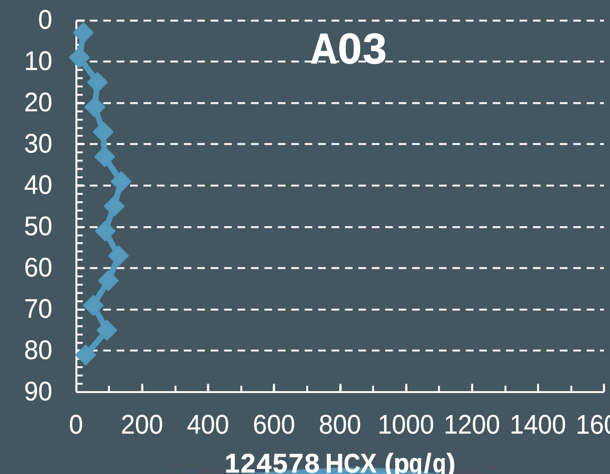




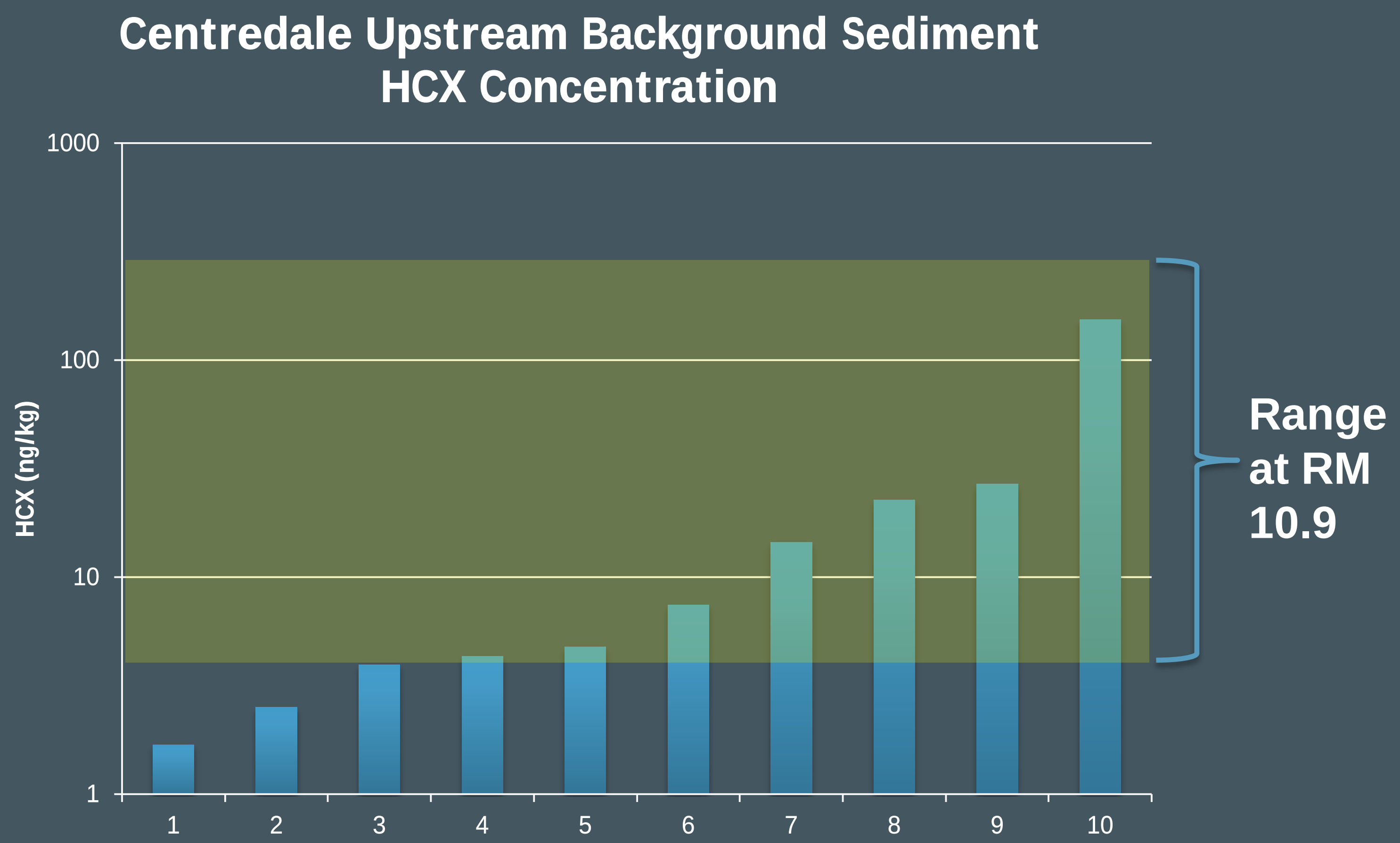
RM 10.9







RM 10.9 HCX Levels Mostly in the Range of Upstream Background at Centredale



Centredale data from RI report; detected values show; detection limit elevated or unclear for ND values

Tierra 2011 Sediment Study – 2,3,7,8-TCDD to HCX

- Tierra does not show its 2,3,7,8-TCDD data
- Using JDG split sample results, ratios indicate:
  - RM 10.9 dioxin much higher than can be ascribed to hexachlorophene manufacture
    - 30 to 400 versus
      - 0.2 to 0.35 at Centredale Manor and 0.01 to 12 at eastern Missouri site
      - 0.4 to 2.3 at RM 11.5 closest to the Givaudan site
  - RM 10.9 not unique relative to downstream sediment
    - 54 & 76 at RM 7.8 compared to 30 to 400 at RM 10.9

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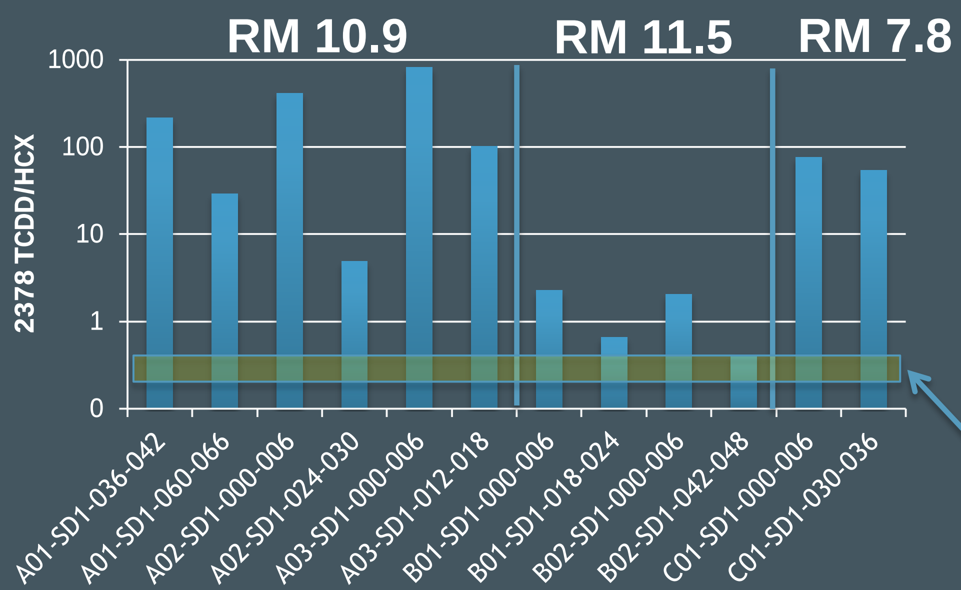
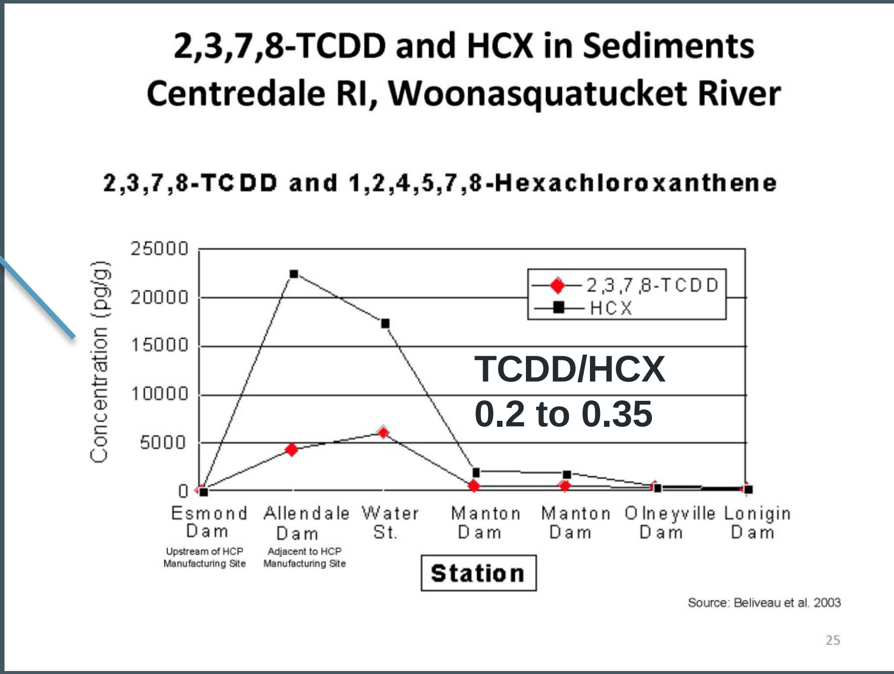
RM 10.9 Has Much More TCDD Than Expected Based on Centredale Data





Tierra Spatial Pattern of 2,3,7,8-TCDD is Misleading

- Compares 1995 and 2008 data, despite concentration changes due to burial & inconsistent patterns
- Connects peaks, ignoring underlying patterns
- Relies on surface sediment data, which cannot be used to assess spatial patterns
  - Concentrations depend on burial rate
  - Comparing sediments of different ages
  - Include samples from locations where sediments did not accumulate

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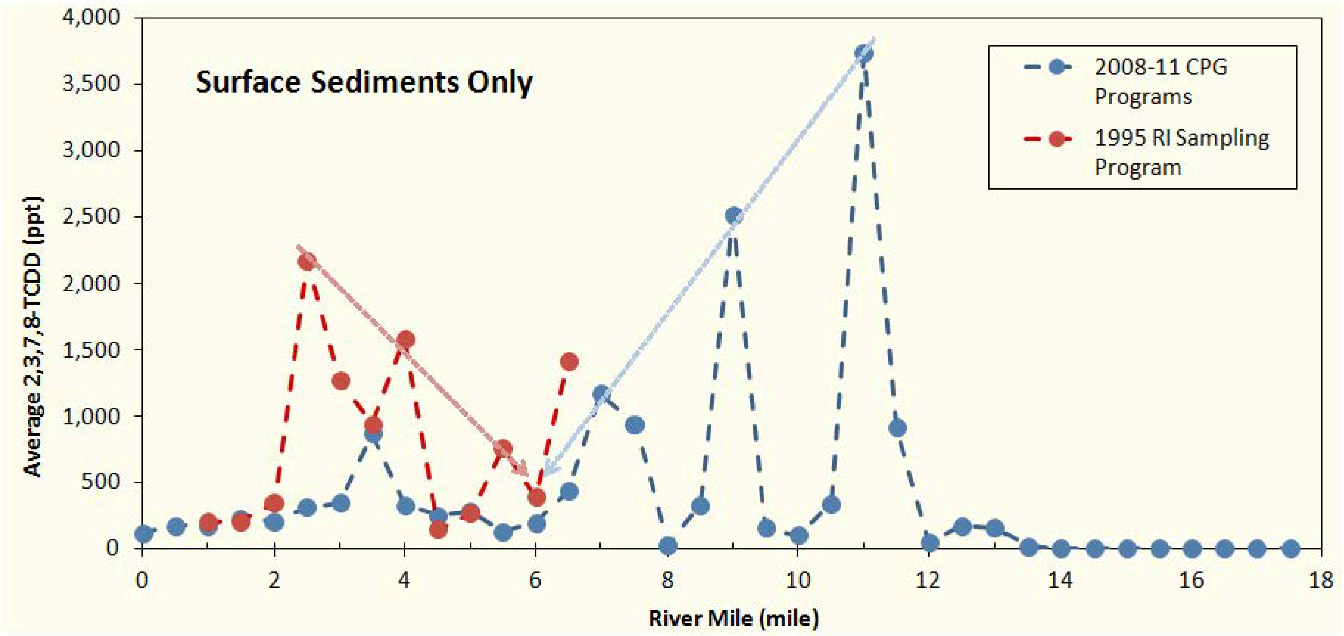
Tierra Plot Shows Confusing Pattern of Peaks and Valleys

Longitudinal Trend—Surface Sediments from 1995 RI and 2008–2011 Programs (Averages)

2,3,7,8-TCDD concentrations averaged over every 0.5 RM



Note: 2008-2011 CPG Programs include 2008 CLRC, 2009/10 Benthic Survey, & 2011 RM 10.9 programs

48

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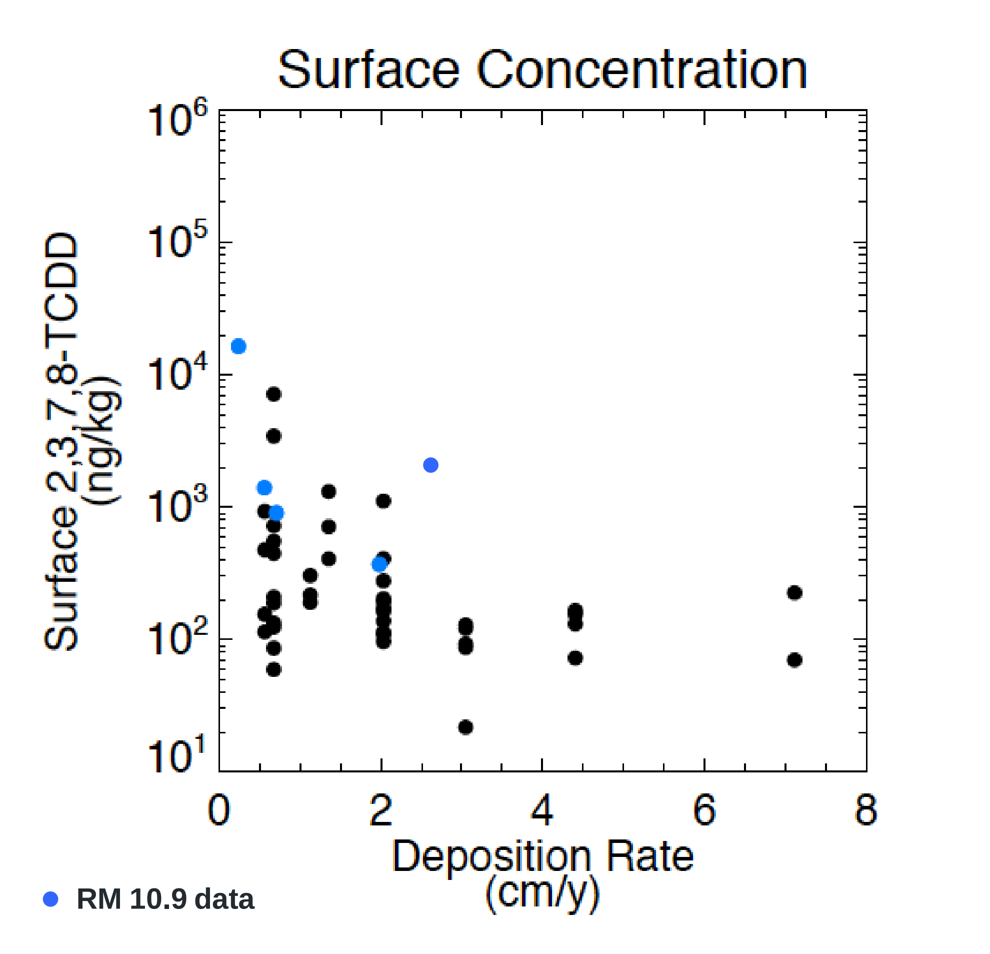
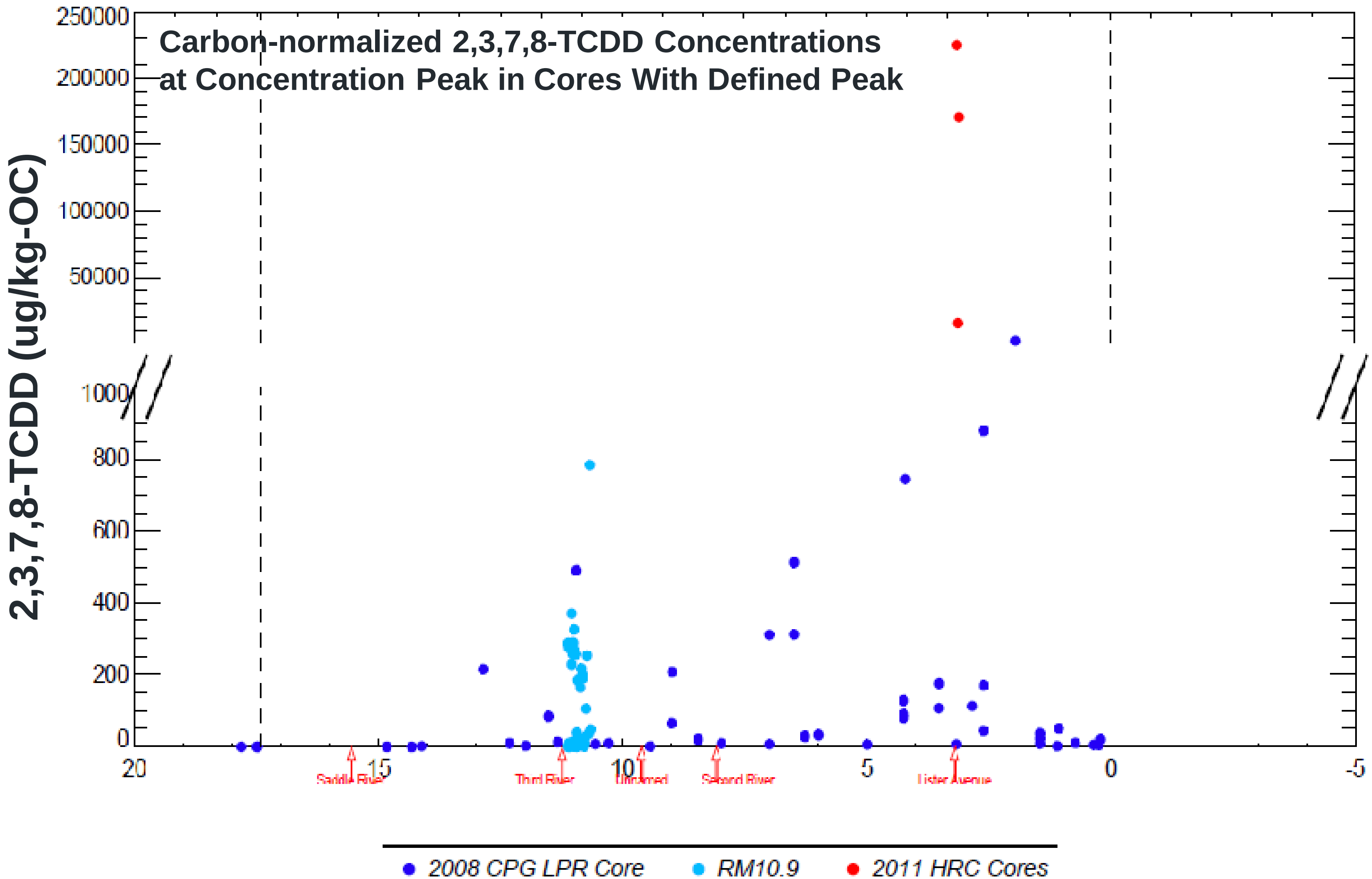
LRC and RM 10.9 Data Show Dependence of Surface Concentration on Burial Rate

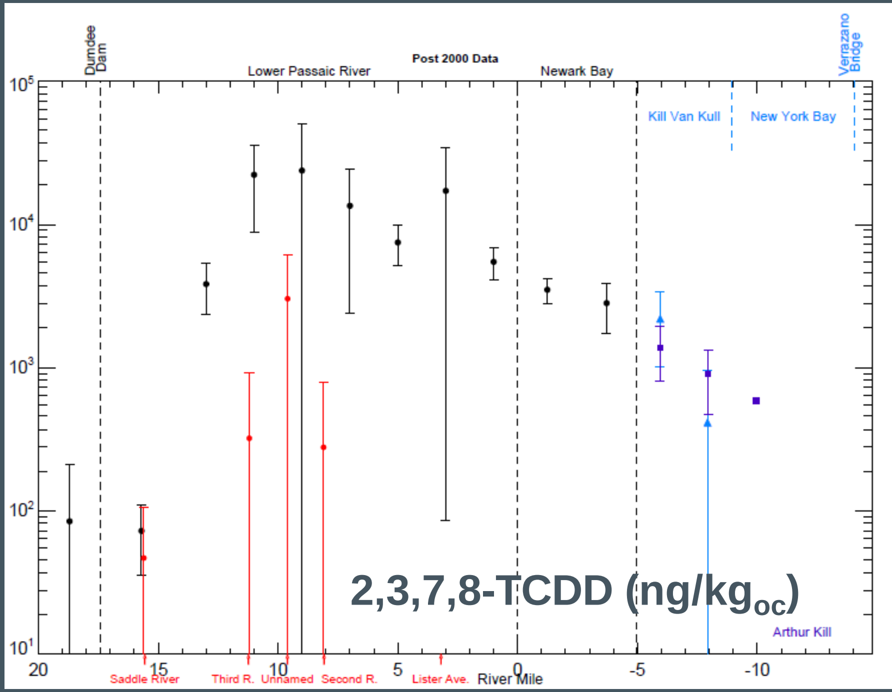


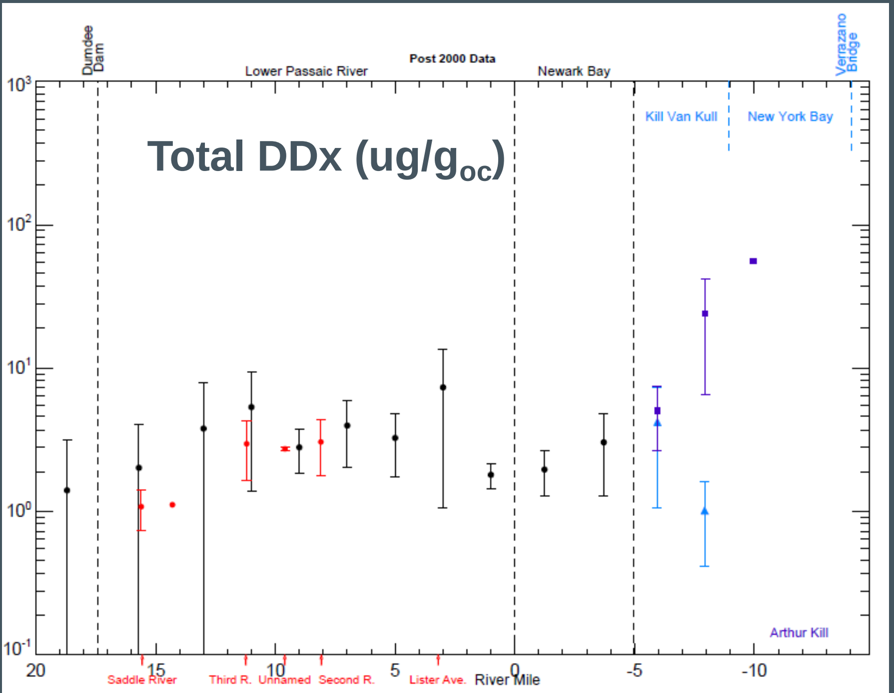
Peak Sediment 2,3,7,8-TCDD Concentrations at RM 10.9 Are Consistent With the Overall Spatial Pattern

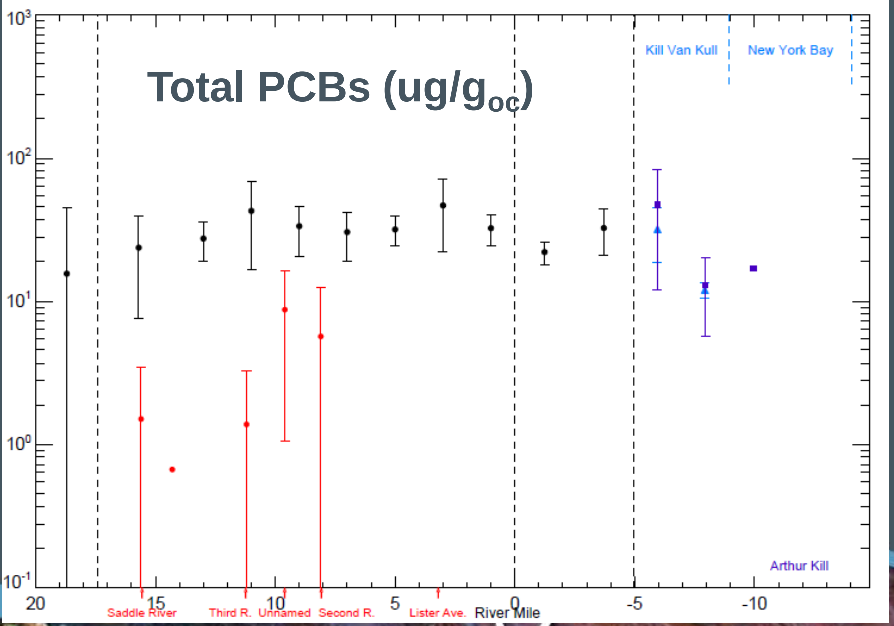


REGIONAL BACKGROUND LEVELS

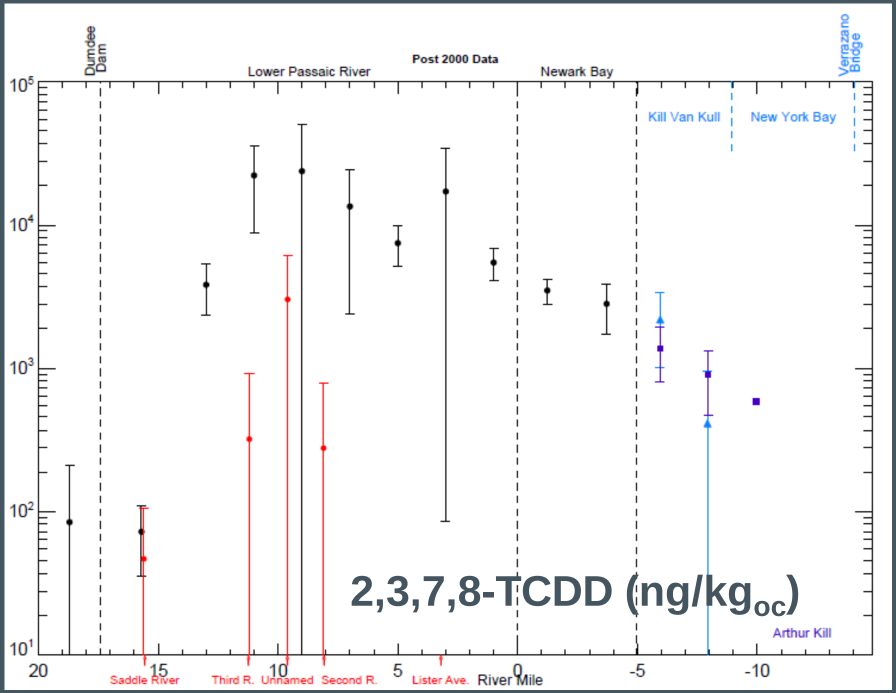
Surface COPC Trends

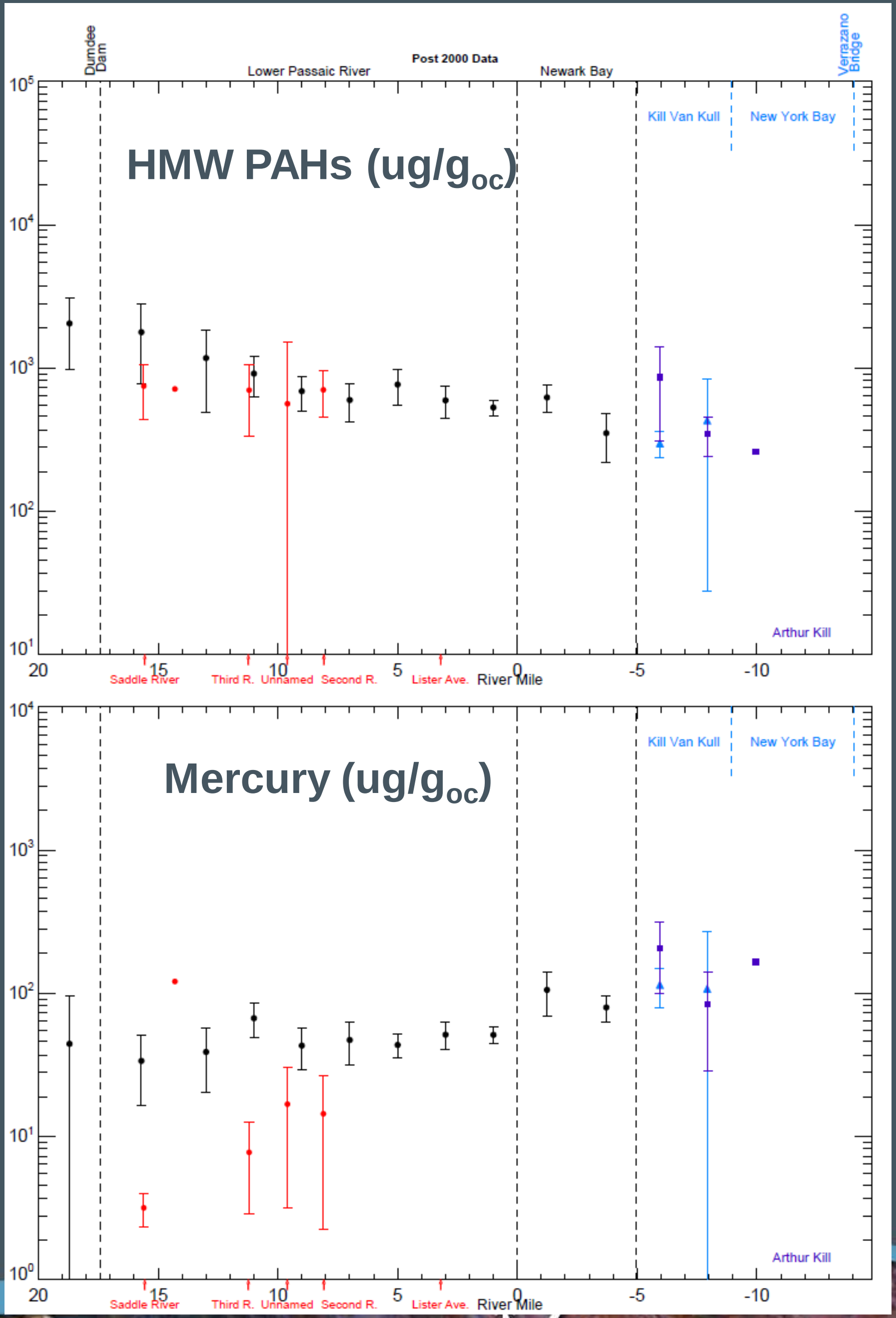






Surface COPC Trends





Regional COPC Concentrations